The 12th International Circumpolar Remote Sensing Symposium
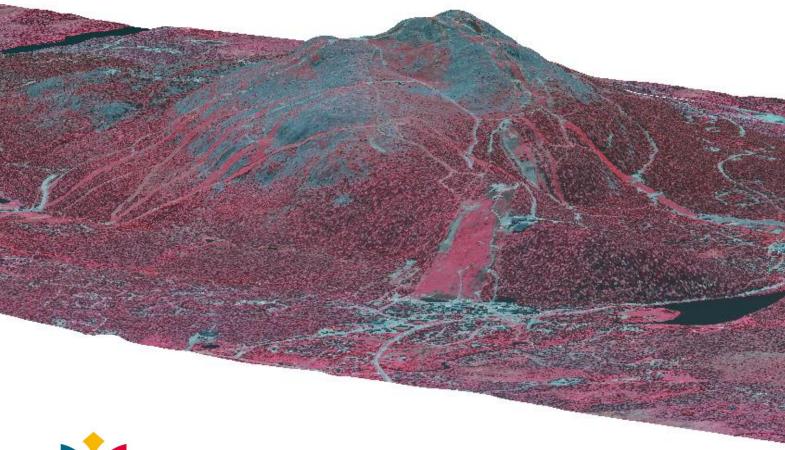
Polar regions in transformation;
climatic change and anthropogenic pressures

UNIVERSITY OF EASTERN FINLAND

USGS
science for a changing world

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Contents

The 12th International Circumpolar Remote Sensing Symposium

Polar regions in transformation; climatic change and anthropogenic pressures

May 14-18, 2012, Levi, Finland

Book of Abstracts

University of Eastern Finland, Department of Geographical and Historical Studies

Words of Welcome

12th Circumpolar Remote Sensing Symposium, Levi, Kittilä, Finland 14 – 18 May 2012

Polar regions in transformation; climatic change and anthropogenic pressures

The Arctic has changed dramatically during the last 50 years, and is changing ever more rapidly. The Arctic wilderness has long been an area with limited access, harsh conditions and little economic value. This has changed, the ever growing demand for natural resources, ores, oil, gas and timber has pushed the economical frontier ever more north. This new interest in northern areas has also strategic implications; the development of the North-West and North-East Passages is of global economic importance, but also poses many threats to Arctic ecosystems. The study of Polar environments is of crucial importance to safeguard ecosystems and manage human interference in these fragile environments.

Remote sensing using both space and airborne instruments is a key element in the exploration and protection of the Arctic and Antarctic, for example, monitoring of carbon flu, ice sheet movement, and changes in vegetation are of global importance. Climate change and its effects on Polar areas is a major topic in Arctic and Antarctic research programs.

2012 is the 40th Anniversary year of the Landsat satellite program, Landsat MSS and TM instruments have provided a historical set of multi-spectral imagery enabling the visualization of the dramatic changes occurring in sub-Arctic and Arctic areas. Several of the presentations during the symposium will illustrate the use of Landsat data in Arctic research.

Remote sensing of Polar areas is however a challenging task, the short summer season, low sun angle and cloudiness are introducing both methodological and logistic difficulties. Therefore remote sensing of high latitudes is a clearly defined field of interest, a fact that was recognized in the late 1980's by Helmut Epp, working in Yellowknife NWT, Canada with the Canada Centre for Remote Sensing. Helmut Epp planned the very first circumpolar remote sensing symposium in 1990 in Yellowknife. The meeting was a big success, 130 people attended the symposium, and the proceedings were published in a special issue of *Arctic* (*Arctic* 1991, Volume 44, Supplement 1). It was decided to organize a symposium every two years in places with an Arctic setting or with a specific Arctic or Antarctic research background. The basic concept of a five day meeting with no parallel sessions is a good concept. There has always been plenty of time for social events and networking, a key element in conference life.

The venue for the 12th symposium, Levi, was chosen for several reasons, first of all it is close to a national airport (Kittilä), but moreover it is situated in Finnish Lapland, and it is a good example of the development going on in the European north. Levi has become one of Finland's major winter tourism resorts, and has seen large scale development. Levi can also be seen as a positive example of regulated compact building, to limit ecological damage. The area is also the location of Europe's largest gold mine, Suurkuusikko, furthermore the area is used for logging and reindeer herding.

Some 42 scholars from 12 different countries covering the entire circumpolar north will gather in Levi to discuss research projects and remote sensing techniques, and, perhaps most important, meet old friends and make new ones.

Alfred Colpaert, professor
University of Eastern Finland
Department of Geographical and Historical Studies

Timo Kumpula, PhD
University of Eastern Finland
Department of Geographical and Historical Studies

Program

The 12th International Circumpolar Remote Sensing Symposium

Venue: Hotel Levi Panorama

Monday 14th May – DAY 1:

5:00 PM   Registration Desk Open in the evening

7:00 PM   Icebreaker at Hotel Levi Panorama

Tuesday 15th May- DAY 2:

9:00   Welcome

Moderator   Annett Bartsch

9:10   **Key note: Thomas Busche**: TanDEM-X: Science Activities

10:00   **Birgit Heim**: User Interaction within ESA DUE PERMAFROST: Evaluation of Circumpolar Remote Sensing Products and their usability for models (permafrost and climate modelling)

10:20   **David Selkowitz**: A Multi-Sensor Approach for Mapping Canopy Height Over Large Areas in Boreal Forest Regions

10:40   Break

11:00   **D.A. Walker**: The evolution of the integrated geobotanical and historical change mapping approach for documenting landscape changes in the Prudhoe Bay oil field, AK, USA

11:20   **Delbart Nicolas**: Remote sensing observations of low-arctic vegetation green-up

11:40   **Marcel Buchhorn**: BRDF Measurements of Low-Growing Vegetation Communities in the Arctic Tundra

12:00   Lunch

Moderator   Allen Pope

1:20   **Florian Tolle**: Monitoring the snow cover on the slopes of a polar glacier basin using terrestrial laser scanning

1:40   **Sonja Kivinen**: Warming climate threatens snowbed and snow patch habitats in northern Finland

2:00   **Eric Bernard**: Where does a glacier end? GPR measurements to identify the limits between the slopes and the real glacier area. Austre Lovénbreen glacier, Spitsberg – 69°N

2:20   Break

2:40   **Arko Lucieer**: Geographic object-based image analysis (GEOBIA) of Worldview-2 imagery of Heard Island for sub-Antarctic vegetation mapping

3:00   **M. Raynolds**: Landsat NDVI trends and related ground data from tundra vegetation in the Upper Kuparuk River Basin, North Slope, Alaska, 1985-2009

3:20   **Jess Grunblatt**: Mapping Late Winter Liquid Water Availability in Alaska North Slope Lakes Using Synthetic Aperture Radar (SAR)

3:40   End of Day 2

             Dinner at own expense

Wednesday 16th May - DAY 3:

8:45   Welcome

Moderator   Petri Pellikka

9:00   **Håkan Olsson**: Mapping of mountain birch in the sub-arctic area using airborne laser scanning and SPOT data

9:20   **Bernt Johansen**: Mapping the Length of the snow free seasons 2000-2010 in Northern Fennoscandia using MODIS data

9:40   **Birgit Heim**: Hyperspectral Arctic VEGetation Indices

10:00   **Anna Maria Trofaier**: Comparison of active microwave and optical imagery over the Yamal Peninsula as a validation technique for radar lake classification

10:20   **Break**

10:40   **Annett Bartsch**: Remote sensing and multi-scale integration for investigating 'Changing permafrost in the Arctic and its global effects in the 21st century—PAGE21

11:00   **Birgit Heim**: Application of the remote-sensing data to permafrost mapping: a case study in Central Yamal

11:20   **Bernt Johansen**: The relationship between phytomass, NDVI and vegetation communities on Svalbard, Arctic Norway

11:40   **Lunch**

12:30   Afternoon excursion to Sodankylä Geophysical Observatory

8:00   **Dinner at own expense**

Thursday 17th May - DAY 4:

9:00   Welcome

Moderator **Howard Epstein**

9:20   **J.R. Harris**: A Robust, Cross Validation Classification Method (RCM) for Improved Mapping Accuracy and Confidence Metrics

9:40   **Timo Kumpula**: Anthropogenic and natural land use and land cover changes in tundra environments detected from satellite image time series on Yamal Peninsula, Russia.

10:00   **Vladimir B. Zabavnikov**: Use of Airborne LIDAR for Research Carrying Out in the Interest of Fisheries Oceanography Information Ensuring

10:20   **Break**

10:40   **Vladimir B. Zabavnikov**: Research of the White/Barents Seas Harp Seal Population on Whelping Patches with Use of Multispectral Air Surveys

11:00 **Raimo Sutinen**: Paleo-landslides in the Suasselkä fault-zone, Finnish Lapland, derived from LiDAR data

11:20 **Madeline Dana Lee**: Image and data processing of airborne geophysics for geological mapping and mineral exploration: Case study from the Wopmay Orogen, N.T., Canada

11:40 **David Selkowitz**: A Multi-Sensor Approach for Synthesizing High Resolution Daily Snow Covered Area

12:00 **Lunch**

Moderators **Gerald Frost & Donald Walker**

1:20 **Howard Epstein**: Climate and grazing influences on circumpolar dynamics of arctic tundra vegetation, using NDVI-biomass relationships

1:40 **Tarmo Virtanen**: The study of fragmented nature of Tundra landscape and its biomass using different resolution satellite images

2:00 **Annett Bartsch**: An new medium resolution datasets of seasonal wetland dynamics from ENVISAT ASAR for northern Eurasia

2:20 **Arko Lucieer**: Using a micro-UAV for ultra-high resolution multi-sensor observations of Antarctic moss beds

2:40 **Break**

3:00 **J.R. Harris**: A review of hyperspectral remote sensing research for geological mapping and exploration of Canada's North

3:20 **Maarit Middleton**: Hyperspectral imaging of boreal peatland biotopes along soil moisture and fertility gradients

4:00-6:00 **Posters**

7:00 **Conference banquet**

Posters

Bruce Forbes: Eurasian Arctic Greening Reveals Teleconnections and the Potential for Novel Ecosystems

Gerald V. Frost: Expansion and patch dynamics of alder shrublands in the Siberian Low Arctic: evidence from remote-sensing spanning the Space Age

Sonja Kivinen: Land use/cover changes and their effects on reindeer husbandry in northern Finland over the past four to six decades

Stein Rune Karlsen: Use of MODIS data to analyse spectral properties of land cover types for improved mapping of the growing season in Northern Fennoscandia

Ottlé Catherine: Remote sensing assessment of the feedbacks between the climatic, environmental and societal changes in Siberia over 30 years: the CLASSIQUE project

H.A.J. Russell: An Emerging Paradigm for Surficial Geological Mapping of Arctic Canada at the Geological Survey of Canada

J.R. Harris: A strategy for producing predictive bedrock maps of Canada's North

M. Raynolds: Sixty years of landscape change within an arctic oilfield, Prudhoe Bay, Alaska

Hailong Zhang: Mapping downward shortwave radiation using MODIS atmospheric products

Yuri Dvornikov: Application of the remote-sensing data to permafrost mapping: a case study in Central Yamal

Arko Lucieer: Texture-based random forest classification of sub-Antarctic vegetation on Macquarie Island from QuickBird and WorldView-2 imagery

A. Pope: Integrating Airborne Thematic Mapper and in situ data to better characterise glacier facies

Timo Kumpula: Time series of aerial photographs as a proxy of vegetation change in boreal peatlands

Timo Kumpula: Palsa decay studied with aerial photography and RTK GPS measurements

Hans Tømmervik: Detection of human induced disturbances and grazing impacts on tundravegetation state: preliminary results of a large scale comparative remote sensing study

Friday 18th May - DAY 5:

8:45   Welcome

Moderator Gareth Rees

9:00   **E. Ranisavlievic**: A dynamic and generic cloud computing model for environmental analysis using in-situ sensing data applied to glacier mass balance analyse (Mer de Glace, Chamonix; East Loven Glacier, Spitsberg)

9:20   **Christine Wesche**: Polarimetric analyses of dominant radar backscattering mechanisms for iceberg detection

9:40   **V.V. Elsakov**: The climatic fluctuation effects of last 30-years to cryolithozone ecosystems in Russian Arctic. Remote sensing approaches.

10:00   **Håkan Olsson**: Investigating topographic normalization, satellite data source and classification method for alpine vegetation mapping in a sub-arctic area of Sweden

10:20   Break

10:40   **Vladimir B. Zabavnikov**: The Barents Sea Marine Environment Air-Space Monitoring in Hydrocarbon Raw Materials Extraction and its Transportation

11:00   **Arko Lucieer**: Texture-based random forest classification of sub-Antarctic vegetation on Macquarie Island from QuickBird and WorldView-2 imagery

11:20   **J.R. Harris**: A strategy for producing predictive bedrock maps of Canada's North

11:40   Concluding Remarks/End of Symposium

12:00   Lunch at own expense

1:20   Departure

Abstracts of Oral presentations

TanDEM-X: Science Activities

Irena Hajnsek, German Aerospace Center, Microwaves and Radar Institute, Germany &
ETH Zurich, Institute of Environmental Engineering, Switzerland
Thomas Busche, German Aerospace Center, Microwaves and Radar Institute, Germany

Abstract

In this paper the status of the science activities and data acquisition strategy as well as the results in terms of demonstration of innovative techniques during the commissioning phase of TanDEM-X will be presented. The focus is on the secondary goals of TanDEM-X that are assigned for data acquisition during the digital elevation model data acquisition phase and the third year of the mission time life. A variety of scientific experiments have been planned to be performed already during the commissioning phase. The scientific experiments are related to bistatic processing, Polarimetric SAR Interferometry, double differential SAR Interferometry, decorrelation measurements, super resolution and velocity measurements. The data quality and the results obtained will be validated and are discussed.

1 Introduction

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) is an innovative spaceborne radar interferometer that is based on two TerraSAR-X radar satellites flying in close formation. The primary objective of the TanDEM-X mission is the generation of a consistent global digital elevation model (DEM) with an unprecedented accuracy, which is surpassing the new HREGP specification defined by NIMA, USA.

Beyond that, TanDEM-X provides a highly reconfigurable platform for the demonstration of new radar imaging techniques and applications [1,2]. Both satellites will then act as a large single-pass radar interferometer with the opportunity for flexible baseline selection. This enables the acquisition of highly accurate cross- and along-track interferograms without the inherent accuracy limitations imposed by repeat-pass interferometry due to temporal decorrelation and atmospheric disturbances.

This paper is focusing on the results of the first announcement of opportunity for user specific acquisition requests and the first demonstration of scientific experiments during the commissioning phase and the operational DEM data acquisition phase in space. The key elements are the bistatic data acquisition employing an innovative phase synchronization link, a novel satellite formation flying concept allowing for the collection of bistatic data with short along-track baselines, as well as the use of new interferometric modes for system verification and DEM calibration. Beside this new modes as along-track SAR interferometry, polarimetric SAR interferometey (Pol-InSAR), digital beamforming, superresolution etc will be performed for the demonstration of innovative technology but also to use it as a tool for the development of new application products.

2 Announcement of Opportunity for Science Data Takes

An Announcement of Opportunity for TanDEM-X user specific data request has been launched mid of July and was closed end of October 2010. During these months the science coordination obtained a high amount of scientific proposals that had high interest for complex coregistered interferometric SAR data. The results and also the outcome of the science proposal evaluation will be presented.

3 Operating Modes

Interferometric data acquisitions with the TanDEM-X satellite formation can be achieved in three cooperative modes: Bistatic, Pursuit Monostatic, and Alternating Bistatic. The three cooperative modes can be further combined with different TerraSAR-X and TanDEM-X SAR imaging modes such as Stripmap, ScanSAR, and Spotlight, the latter being in sliding spotlight acquisition geometry. However, only the bistatic mode will be used for the acquisition of standard TanDEM-X DEM products, while others are used for system calibration, validation and verification as well as for the acquisition of non-operational experimental data [1].

Summary

In this paper the outcome of the Announcement of Opportunity, the data collection since April 2011 and the data quality are discussed and summarized.

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[2] Krieger, Gerhard und Moreira, Alberto und Fiedler, Hauke und Hajnsek, Irena und Werner, Marian und Younis, Marwan und Zink, Manfred (2007) TanDEM-X: A Satellite Formation for High Resolution SAR Interferometry. IEEE Transactions on Geoscience and Remote Sensing , 45 (11) , Pages 3317-3341. IEEE . DOI: 10.1109/TGRS.2007.900693.

[3] S. Baumgartner, G. Krieger and K.-H. Bethke, "A Large Along-Track Baseline Approach for Ground Moving Target Indication Using TanDEM-X," Proceedings of International Radar Symposium (IRS), Cologne, Germany, 2007.

User Interaction within ESA DUE PERMAFROST: Evaluation of Circumpolar Remote Sensing Products and their usability for models (permafrost and climate modelling)

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The ESA DUE Permafrost project (2009-2012) developed a suite of remote sensing products indicative for the subsurface phenomenon permafrost: Land Surface Temperature (LST), Surface Soil Moisture (SSM), Surface Frozen and Thawed State (Freeze/Thaw), Terrain, Land Cover, and Surface Water. Snow parameters (Snow Extent and Snow Water Equivalent) are being developed through the DUE GlobSnow project (Global Snow Monitoring for Climate Research, 2008-2011). The final DUE Permafrost remote sensing products cover the years 2007 to 2011 with a circumpolar coverage (north of 50°N). The products are released in early 2012, to be used to analyze the temporal dynamics and map the spatial patterns of permafrost indicators. Further information is available at *www.ipf.tuwien.ac.at/ permafrost*.

Since the beginning, scientific stakeholders and the International Permafrost Association (IPA) were involved in the science plan. Interactive User Workshops took place in 2010 at the Technical University of Vienna, Vienna (AT), and in 2011 at the International Arctic Research Center (IARC), Fairbanks, Alaska (US). The final User Workshop was held between Feb 15-17 2012 at the Alfred-Wegener-Institute for Polar and Marine Research (AWI) in Potsdam. It brought together a multidisciplinary permafrost community working on satellite-derived products, in-situ field validation and modelling. About 60 participants from Austria, Canada, Finland, France, Germany, Italy, Japan, Norway, Poland, Russia, Sweden Switzerland, UK, and USA participated and gave oral and poster presentations.

The involvement of the user communities and the ongoing evaluation of the indicators derived from remote sensing data for high-latitudinal permafrost regions make the DUE Permafrost products trustworthy for the permafrost and the climate research community. Ground data is provided by user groups and global networks. A major part of the DUE Permafrost core user group is contributing to GTN-P, the Global Terrestrial Network of Permafrost (IPA). Its main programmes, the Circumpolar Active Layer Monitoring (CALM) and the Thermal State of Permafrost (TSP) has been extended during the last International Polar Year (2007-2008) to provide a true circumpolar network. Ground data ranges from active layer- and snow depths, to air-, ground-, and borehole temperature data as well as soil moisture measurements and the description of landform and vegetation.

The adaption of the remote sensing products for the permafrost and climate modelling is experimental. For a few years already, the Geophysical Institute Permafrost Laboratory (GIPL), University of Alaska Fairbanks, US

(http://www.gi.alaska.edu/research/snowicepermafrost/Permafrost) has successfully demonstrated the value of using LST derived from remote sensing data for driving its permafrost models. Further experimental testing of the use of DUE Permafrost products for the permafrost-modelling and climate-modelling communities will range from (i) the evaluation of external data of the models, with modifying or providing new external data (e.g. tundra land cover, surface water ratio, soil distribution), to (ii) new drivers for regional models derived from remote sensing data (e.g., LST), to (iii) the evaluation of the output data from the models (e.g. spatial patterns of moisture and temperature).

A Multi-Sensor Approach for Mapping Canopy Height Over Large Areas in Boreal Forest Regions

David Selkowitz

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Spatially explicit representations of vegetation canopy height over large regions are necessary for a wide variety of inventory, monitoring, and modeling activities. Although airborne lidar data has been successfully used to develop vegetation canopy height maps in many regions, for vast, sparsely populated regions such as the boreal forest biome, airborne lidar is not widely available. An alternative approach to canopy height mapping in areas where airborne lidar data is limited is to use spaceborne lidar measurements in combination with multi-angular and multi-spectral remote sensing data to produce comprehensive canopy height maps for the entire region. This study uses spaceborne lidar data from the Geosciences Laser Altimeter System (GLAS) as training data for regression tree models that incorporate multi-angular and multi-spectral data from the Multi-Angle Imaging Spectroradiometer (MISR) and the Moderate Resolution Imaging SpectroRadiometer (MODIS) to map vegetation canopy height across a 1,300,000 km^2 swath of boreal forest in Interior Alaska. Results are compared to *in situ* height measurements as well as airborne lidar data. Although many of the GLAS-derived canopy height estimates are inaccurate, applying a series of filters incorporating both data associated with the GLAS shots as well as ancillary data such as land cover can identify the majority of height estimates with significant errors, resulting in a filtered dataset with much higher accuracy. Results from the regression tree models indicate that late winter MISR imagery acquired under snow-covered conditions is effective for mapping canopy heights ranging from 5-15 m, which includes the vast majority of forests in the region. It appears that neither MISR nor MODIS imagery acquired during the growing season is effective for canopy height mapping, although including summer multi-spectral MODIS data along with winter MISR imagery does appear to provide a slight increase in the accuracy of resulting height maps. The finding that winter, snow-covered MISR imagery can be used to map canopy height is important because clear sky days are nearly three times as common during the late winter period as during the growing season. The increased odds of acquiring cloud-free imagery during the target acquisition period make regularly updated forest height inventories for Interior Alaska much more feasible. A major advantage of the GLAS-MISR-MODIS canopy height mapping methodology described here is that this approach uses only data that is freely available worldwide, making the approach potentially applicable across the entire circumpolar boreal forest region.

The evolution of the integrated geobotanical and historical change mapping approach for documenting landscape changes in the Prudhoe Bay oil field, AK, USA

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Monitoring changes related to resource development is a key for future planning and sustainable management of Arctic natural resources. The Integrated Geobotanical and Historical Change Mapping (IGHCM) approach evolved between 1970 to the present to document land-cover and land-use changes associated with the Prudhoe Bay oil field, AK. The maps portray changes to the terrain since 1949 up to the modern industrial complex. Some of the key historical events include:

1) Regular aerial-photograph surveys. In 1948-49 the U.S. Navy photographed much of the Arctic Slope from the air to help assess the region's oil potential (USN 1948, 1949 BAR photographs). This was followed by numerous aerial-photograph surveys taken by government agencies and the oil industry (Army Map Service 1955; ARCO 1968; USGS 1970, Sohio 1973; NASA 1974, 1977, 1982; Air Photo Tech (U.S. Tundra Biome) 1972, 1973; Prudhoe Bay Unit 1977-2011).

2) High-resolution topographic maps. Early on, the oil industry committed to maintaining complete aerial-photographic and topographic map coverage of oil fields portraying all infrastructure, hydrologic features and topography at 1:6000 scale and 0.5 m vertical resolution. This led to the modern highly accurate geographic information system utilizing photogrammetric orthophoto and topographic mapping developed by Aerometric, Inc.

3) Geobotanical mapping method. Research by the International Biological Programme, Tundra Biome in the Prudhoe Bay area during the 1970s included extensive soil and vegetation mapping (Brown et al. 1975, Everett 1975, Webber and Walker 1975), ultimately leading to development of the geobotanical mapping methods and the *Geobotanical Atlas of the Prudhoe Bay Region, Alaska* (Walker et al. 1980), which combined mapping of soils, landforms, and vegetation in a single integrated map.

4) Use of GIS to combine geobotanical maps with history of change. A study by the US Fish and Wildlife Service to assess cumulative effects of oil development on breeding shorebird habitat led to the IGHCM method. The map database included eight geobotanical variables, and 15 years (1968-1983) of land cover changes (Walker et al. 1986a, b, 1987). This project used the integrated-terrain-unit mapping (ITUM) approach of the Environmental Systems Research Institute (ESRI, Dangermond et al. 1982).

5) NRC inventory of oil-field infrastructure on the North Slope. In 2001, the U.S. Congress asked the National Research Council (NRC) to conduct an assessment of the cumulative effects of oil and gas activities on Alaska's North Slope. The study used information in the

oil industry's geographic information system (GIS) of the oil field and a time-series of aerial photographs to show the progressive increase in infrastructure for the entire network of oil fields on the North Slope from 1968-2001 (Ambrosius 2002).

6) <u>Updating the maps to 2010</u>. The most recent analysis is an update of IGHCM approach applied to Map 32 from the Walker et al. (1986, 1987) study. This 25 km^2 area includes the Tundra Biome study area (Webber and Walker 1975). This part of an NSF Maps and Locals (MALS) project that will use such maps to assess local people's perceptions of the changes on the North Slope (Raynolds et al. 2012, this conference).

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Remote sensing observations of low-arctic vegetation green-up

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One of the reported changes in arctic ecosystems in response to warming climate is the advance of the leaf appearance in spring.

We developed a remote sensing methodology, using NOAA/AVHRR and SPOT/VGT, able to measure the timing of the deciduous tree leaf appearance without being affected by snow, as shown by the comparison with *in situ* observations recorded in Siberian taiga ecosystems (RMSE=8 days). This methodology was then applied to the tundra Toolik Lake station. For the 4 years of *in situ* observations, the absolute difference between the remote sensing green-up dates and the ground observations of the date of leaf appearance of *betula nana* ranges from 1 to 6 days.

We applied a phenological degree-day model, initially calibrated for taiga, to the whole low-arctic tundra. This model reproduced the ground observations with an absolute error ranging from 2 to 7 days. Then, we compared the simulated green-up dates with the green-up dates obtained from satellite observations. The model, although calibrated for taiga, performs remarkably well in tundra, with a root mean square difference with remote sensing green-up date ranging from 4 to 8 days for most of the tundra region. Moreover, the model can reproduce the interannual variations that are detected by remote sensing, with a correlation factor ranging from 0.74 to 0.84 and a root mean square difference of less than 4.6 days when averaged over large regions. This confirms that air temperature is the key factor controlling spring leaf phenology in tundra.

The leaf appearance model and the satellite observations reveal that leaf appearance has tended to occur earlier by approximately 10 days both in Alaska since 1975, and in west Siberian tundra since 1965.

We will then present time series analysis of phenology on the Abisko Tundra and Birch Forest sites as detected by remote sensing.

BRDF Measurements of Low-Growing Vegetation Communities in the Arctic Tundra

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Imaging data from satellite systems with sensor pointing capabilities such as CHRIS/Proba, RapidEye, or sensors with wide swath, such as AVHRR, MODIS, and MERIS, is influenced by the bidirectional reflectance distribution function (BRDF). This effect can cause significant changes in the measured spectral surface reflectance depending on the solar illumination geometry and sensor viewing conditions.

The Environmental Mapping and Analysis Program (EnMAP), a German hyperspectral mission with expected launch in 2015, will provide high spectral resolution observations with a ground sampling distance of 30 meters. Since the EnMAP sensor has pointing capabilities, both spectral and directional reflection characteristics need to be taken into account for the algorithms development for vegetation parameters of low-growing tundra landscapes. The AWI-project 'hyperspectral method development for Arctic VEGetation biomes' (hy-Arc-VEG) is part of the national preparation program for the EnMAP mission. Therefore, the Alfred-Wegener-Institute (AWI) developed a portable field spectro-goniometer, named EyeSight, for the in-situ measurements of anisotropic effects of natural surfaces. The goniometer was designed for field use in difficult terrain and is therefore of low weight and weatherproof. Moreover, the instrument is constructed from low cost building materials and can be disassembled into its components for transport. The current off-nadir viewing capacity is matched to the EnMAP sensor configuration.

We carried out field measurements during the summer field campaign of the Earth Cryosphere Institute (RU) in August 2011 on the Yamal Peninsula, northwestern Siberia, Russia. The field goniometer measurements (conducted under varying sun zenith angles), as well as field spectro-radiometrical measurements, were carried out at the NASA Yamal Land Cover/Land Use Change (NASA Yamal-LCLUC) transects and réleves at Laboravaya (southern Yamal) and Vaskiny Dachi (central Yamal).

BRDF processing for the tundra test sites demonstrate the mirror asymmetry in relative azimuth with respect to the principal plane. It also showed that the maximum scattering appears in the backward direction, but that there is no minimal forward scattering. Instead, the forward scattering is characterized by similar to higher reflectance values compared to the nadir position. Moreover, the analysis of the anisotropic behaviour of moss-dominated tundra types with 10 to 15% vascular plant cover show that the BRDF influence on vegetation indices (VI) of low-growing arctic vegetation communities can be up to 15% of the nadir value. The low sun elevation at the arctic latitudes prevent "hotspot-effects" in EnMAP data, but a BRDF normalization still should be taken into account for the development of tundra-adapted vegetation indices.

More field spectro-radiometrical measurements and BRDF measurements of different arctic vegetation communities are planned for summer 2012 along the North American Arctic Transect (NAAT) in cooperation with the Alaska Geobotany Center of the University of Fairbanks Alaska.

Monitoring the snow cover on the slopes of a polar glacier basin using terrestrial laser scanning

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The processes occurring on slopes in glacier basins do have a key role in the physical and hydrological behavior of polar glaciers. Slopes are impacted by permafrost melting, snow cover and glacier constraints. Slopes also do contribute significantly to hydrological budgets. The combination of these factors lead to complex processes that are not easily accounted for. Acquiring data on slopes is not a straightforward task. To quantify precisely the processes occurring in slopes requires data both spatially and temporally precise enough. Difficulties associated with slopes access do forbid in most cases direct field monitoring of slopes. Terrestrial Laser Scanner (TLS) techniques do seem to allow for fine grain observations at adapted time steps. This study focuses on the Austre Lovenbreen glacier basin located in Svalbard (79°N). This glacier has been studied by French and foreign scientists since the 60's. The amount of data hence already available will be used to criticize and validate the results of this work and will provide valuable contextual elements. TLS data will grant us the possibility to follow precisely slope dynamics. These processes will be observed in different strategic places in the glacier basin such as accumulation and ablation zones, steep or low-angle slopes, corresponding to different settings. A first fieldwork session is planned for this spring. Surface models of slopes will be derived using Lidar equipment. Short term dynamics such as avalanches occurrences will be monitored. Data quality assessment will be conducted as well as direct measurements of the snow height, water equivalent and quality on the slopes. This will provide the snow maximum surface model dataset. A second dataset will be derived at the end of summer and will be used as reference dataset in order to compute the snow volume on slopes. When avalanches will take place, the volume of displaced snow will also be assessed using TLS measurements. Data acquisition fieldwork is planned for late april, as experience from previous years indicate that it is close to the expected annual snow maximum. At this time of year, transportation of TLS equipment will also be facilitated by the use of snowmobiles. Snow drilling campaigns will also be conducted in order to monitor the daily evolution of snow cover, at least in the most accessible parts of the slopes. TLS will be used as many times as possible. Technical characteristics of TLS equipment impose good visibility conditions in order to obtain high quality data sets. Snow or rain precipitations are also not compatible with data acquisition.

Warming climate threatens snowbed and snow patch habitats in northern Finland

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Late-melting snowbeds are classified as near threatened and permanent snow patches as endangered habitats in Finland. We studied interannual variation of late summer snow cover in sub-arctic Enontekiö Lapland, northwestern Finland in years 2000, 2004, 2006, and 2009. Snow cover in 30 m resolution was derived from Landsat TM and ETM+ images obtained between 27 July and 4 August using a normalized difference snow index (NDSI). Variation in climatic conditions in the study region was examined using temperature and precipitation data from 1995 to 2009 and climate scenarios derived from the ENSEMBLES and PRUDENCE simulations.

Late summer snow covered 23.0 km^2 in 2000, 2.7 km^2 in 2004, 1.5 km^2 in 2006, and 5.0 km^2 in 2009 of the 3176.5 km^2 study area. The decline of snow cover was most prominent below 900 meters and on southern and western slopes. In year 2000, approximately a half of the snow cover was found above 900 meters (where 7% of the total study area is located) compared to circa 75% in 2004 and 2006, and 62% in 2009. The interannual variation in late summer snow cover reflects the climatic variation in the study region. The mean annual temperature increased on average by +0.16°C per year during 1995-2009. Warming was most noticeable in November-December and in April-May. Annual snowfall in previous years (three-year moving average) seemed to be related to the observed interannual variation in late summer snow cover. ENSEMBLES models predict the greatest warming to take place in winter, from late autumn to early spring (ca +5.5°C by 2070-2099). Further, PRUDENCE models predict a significant decrease in the number of frost days from an average of 240 in 1961-1990 to 185 in 2071-2100.

The results suggest that future climatic conditions will not support the occurrence of summer snowbeds and snow patches in the study area. This will lead to drier soils at high altitudes and consequently altered hydrology in the area. Snowbed habitats in Finland harbor circa 75 vascular plant species and 48 bryophyte species of which many are rare and dependent on continuous water availability. Reduced soil moisture will lessen bryophyte survival, reduce growth of hydrophilic herbs and graminoids and threaten the species which cannot tolerate drier conditions and heavier competition at lower altitudes. Moreover, the changes in plant abundance and their nutritional value may have cascading effects on ecosystem functioning via their influence on lemmings and reindeer. Snowbeds and permanent snow patches are favored summer habitats by reindeer as they provide insect relief, but also fresh, high-nutritious forage throughout the summer. Reductions in summer snow cover are thus likely to result in alterations in ecosystem services in the landscape.

Where does a glacier end? GPR measurements to identify the limits between the slopes and the real glacier area. Austre Lovénbreen glacier, Spitsberg – 69°N.

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Usually, glacier limits are mapped according to a spatial discrimination. This discrimination is made from remote sensing images or aerial photography. What appears like ice at the warmest time of the year (end of summer) corresponds to the glacier, while what appears as rock is identified as the slope. This kind of visual discretization seems to be insufficient in the case of small arctic glaciers.

Indeed, the slopes have been described as very unstable parts of glacial basins. Debris are generated by the inclination of the slopes, and reach the glacier surface. Thus, the visible limit does not correspond to the real limit: a significant amount of ice is potentially covered, enlarging the glacier surface. Hence, we apply Ground Penentrating RADAR (GPR) measurements in the broader framework of the Hydro-Sensor-FLOWS program for mapping, beyond the central parts of the glacier, the steep slopes—of the Austre Lovén glacier (Spitsberg, 79°N). The goal here is to assess the discrepancy between the aerial images and the GPR data which exhibit significant ice thickness at locations considered outside the glacier itself. Arctic context is most appropriate to this kind of work due to the significant erosion that affects arctic glacial basins.

To identify this "new" limit, we used GPR measurements completing multiple transects orthogonally to the glacier. Those transects provide both quantitative and qualitative information. These measurements allow us to determine where the rock / ice interface is located. Those data then allow for the calculation of the surface and the actual volume of the glacier.

This presentation demonstrates the first steps in this process. Transects were only conducted on four test areas around the Austre Lovénbreen, because of the difficulty in raising the GPR as much as possible in the slope

Geographic object-based image analysis (GEOBIA) of Worldview-2 imagery of Heard Island for sub-Antarctic vegetation mapping

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Heard Island is a pristine sub-Antarctic island south of the Antarctic Polar Frontal Zone in the Indian Ocean. This Australian territory is a 2800 m high volcanic and glaciated island, and because of its remoteness, human visits to the island are very infrequent. Heard Island is unique in terms of its location, climatic conditions, vegetation communities, geology, volcanic activity, and glacial cover. Up-to-date and accurate spatial information is of crucial importance for sustainable management of the island. Because of the island's remoteness, satellite imagery provides advanced and cost-effective means to map its land cover and to quantify environmental changes. This information is important for sustainable management of this pristine island, to study the regional effects of climate change, and to assess the effects of human impacts.

During previous expeditions to Heard Island, terrestrial plant ecology has been studied and vegetation maps have been produced. These maps were produced manually, based on visual interpretation of aerial photographs and satellite imagery, combined with GPS-based field samples. Because of the inaccessibility of Heard Island, field surveys are often expensive and labour intensive, and expeditions can potentially be intrusive. Satellite images have been successfully used in vegetation mapping, monitoring, and ecological applications in the past. Very high spatial resolution imagery (VHR) such as IKONOS, QuickBird, and WorldView-2 (WV2) provide valuable new sources of information for remotely sensed vegetation mapping.

Traditional classification techniques are often pixel-based, i.e. the image is classified pixel by pixel. These classifiers have no spatial 'awareness'. In VHR imagery, this can result in a lot of 'noise' and misclassifications in the classification result. However, relatively recent developments in remote sensing science have adopted geographic object-based image analysis techniques (GEOBIA). In GEOBIA the smallest element that is classified is a segment or object consisting of multiple pixels rather than a single pixel. This study presents a novel GEOBIA approach based on a recent WV2 image of Heard Island. We extract several vegetation indices from the WV2 multispectral bands (2 m resolution) to enhance the sub-Antarctic vegetation communities. We identify a range of texture measure based on the grey level co-occurrence matrix (GLCM) to highlight the spatial patterns in the vegetation communities. In addition, a digital elevation model (DEM) acquired from TerraSAR-X imagery (10 m resolution) is used to derive terrain characteristics, such as topographic wetness, solar radiation, slope, and curvature. The combination of spectral, textural, and terrain features is used to identify image objects that correspond to vegetation communities. We then apply a state-of-the-art random forest classifier to classify the objects and identify the most important variables in the classification. The classifier is trained and validated with field samples. With the proposed technique we developed a robust, repeatable, and ecologically meaningful approach towards classification of sub-Antarctic vegetation communities on Heard Island.

Landsat NDVI trends and related ground data from tundra vegetation in the Upper Kuparuk River Basin, North Slope, Alaska, 1985-2009

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A Landsat time series (1985, 1989, 1995, 1999, 2004, and 2007) was used to analyze changes in the Normalized Difference Vegetation Index (NDVI) in an 800 km^2 area on the North Slope of Alaska. Previous analysis of this area at a coarser spatial scale showed increasing NDVI for this same time period (AVHRR 12.4 km pixels) (Bhatt et al. 2010). The 30-m Landsat pixel resolution demonstrated that the increase in NDVI was not uniform across the landscape, but varied with elevation, glacial surface and vegetation type.

Landsat scenes were selected that were relatively cloud-free over the study area during peak growing season (29 July – 16 August). Reflectance was calculated for the Landsat sensor data, which was then normalized to an index year with no cloud cover (1985), using light and dark pseudo-invariant features (Chen et al. 2005). NDVI was calculated ((NIR - R)/ (NIR + R)) (Tucker 1979). Water, clouds, shadows and missing data were masked for each image and eliminated from the analysis. A simple linear regression was used to determine the trend in NDVI and its significance for all pixels with at least 5 years of data. NDVI trends were analyzed by elevation, hill-slope and aspect (Nolan 2003) and by mapped categories of vegetation type, surficial geomorphology, surficial geology and glacial geology (Walker and Maier 2008).

Average NDVI of the study area increased significantly ($p < 0.05$) over the time period, at a rate of 0.006 NDVI units/decade, a 2.6% increase in NDVI over the 22 years. 89% of the area showed no significant change, 10% a significant increase in NDVI, and 1% a significant decrease in NDVI. The highest rates of NDVI increase and decrease were on revegetating and eroding areas, respectively (both natural and anthropogenic). NDVI trends decreased with elevation and the slope of the surface. The most recent advance of each glacial period showed smaller NDVI increases than earlier advances.

Environmental and cover characteristics were collected at 53 ground plots within the study area with differing NDVI trends. Multivariate analyses (principal components analysis and regression tree analysis) were used to determine the most important physical and biological factors affecting NDVI trends. The results emphasized the importance of elevation and glacial geology. Vegetation type and cover of particular plant growth forms (such as crustose lichens, acrocarpous mosses and depth of peat) were somewhat less important. Physical characteristics such as aspect, slope, soil moisture and texture, and surface geomorphology were of minor importance in determining the magnitude of NDVI trends.

This study emphasized the importance of large-scale landscape patterns, such as differing glacial surfaces, in controlling changes in tundra vegetation in the study area. We plan to repeat our study at other sites on the North Slope to help clarify the importance of variation in physical and biological factors in the absence of mountain glaciation.

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Mapping Late Winter Liquid Water Availability in Alaska North Slope Lakes Using Synthetic Aperture Radar (SAR)

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The North Slope coastal plain is characterized by permafrost and an immense number of freshwater lakes. These lakes provide important habitat for fish and wildlife species and supply freshwater for industrial development. During winter, shallow lakes on the coastal plain typically freeze to the bottom. These lakes cannot serve as fish overwintering habitat or be pumped for industrial fresh water uses. Consequently winter liquid water availability is an important parameter of lake resource function.

Although synthetic aperture radar (SAR) has been used in a variety of local studies to differentiate shallow lakes that freeze to the bottom from those that are deep enough to maintain winter liquid water availability, no regional assessment has been performed. The goal of this study was to map winter liquid water availability throughout the North Slope coastal plain.

Thirty-six late winter (April) 2009 ERS-2 SAR images were acquired for the 168,000 sq km study area. Data for this imagery was calibrated and resampled to a 12.5m pixel. The imagery was orthorectified using the USGS National Elevation Dataset (NED) and precision registered to an orthoimage base. National Hydrology Dataset (NHD) lake perimeters were used to extract data values from the SAR imagery and image processing techniques were used to classify the extracted SAR data values into a frozen (shallow lake-grounded ice) and unfrozen class (deep lake-floating ice). Classification results were compiled to form a single GIS data layer of late winter liquid water availability for North Slope coastal plain lakes. A total of 158,467 lakes were classified using SAR data. Of these 21% contained some unfrozen area while 17% had greater than 20% of their total surface area classified as unfrozen.

Lake bathymetric transect data from previous research (2008-2009) were compiled for 25 lakes. A second verification data set was compiled from field observation (1993) of maximum depth for 107 lakes. Ice depths for North Slope lake ice were identified within the literature and a generalized minimum ice depth (1.6m) and maximum ice depth (2.0m) were identified.

Bathymetric sample locations were assigned as frozen/unfrozen based on the SAR classification results for that location. The unfrozen area of lakes was buffered inward 50m to account for potential unfrozen sediments, mixing and/or misregistration. Of the bathymetric locations that were classified as frozen (n=752), 93% had depths less than 1.6m and 96% had depths less than 2m. For buffered bathymetric locations classified as unfrozen (n=973), 94% were greater than 1.6m depth and 83% were greater than 2m.

Decision rules were developed to identify a lake as frozen/unfrozen based on maximum depth value and the SAR analysis results. Lakes identified as frozen by maximum depth measurement were similarly identified by the SAR classification in 91% of the lakes while 87% of the lakes identified as unfrozen by maximum depth were identified by SAR as unfrozen.

Mapping of mountain birch in the sub-arctic area using airborne laser scanning and SPOT data

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Airborne laser scanning (ALS) is currently being carried out for all of Sweden. The primary purpose is to construct a new national digital elevation model (DEM). In addition, the ALS data are also expected to be a valuable resource for vegetation mapping and monitoring. A test area for national scanning in the mountain area is located around Abisko (68° 23' N, 18° 53' E). This contribution summarizes results from some of our recent and ongoing remote sensing studies in this area related to vegetation mapping and biomass monitoring of the tree line ecotone between tundra and mountain birch (*Betula pubescens* ssp. *czerepanovii* (Orlowa)). The ALS data were scanned with an Optech ALTM Gemini-scanner and a posting density of 1.4 returned pulses m^{-2}. In addition, SPOT multispectral satellite data have been used in two of the studies. The remote sensing data have been trained using field surveyed sample plots.

An important task is to define forest areas that fulfill the FAO criteria for forest (tree height > 5 m and crown cover > 10%). A supervised classification of gridded ALS data provided an overall accuracy of 92% (Lindgren 2012) when mapping FAO forest and two non-forest classes.

Using the same ALS data, prediction of birch forest height, canopy closure and biomass provided a plot level RMSE of 9.5%, 18.7%, and 21.2%, respectively (Nyström et. al 2012). Work is currently being completed to extend the birch forest biomass mapping by combining SPOT satellite data with the ALS data.

Classification of vegetation types in the tundra-birch forest ecotone into eight vegetation classes using a combination of ALS and SPOT 4 data (20 m pixel) gave an overall accuracy of 81.4 %, compared to 75.6% when only satellite data were used (Nordkvist et. al, 2011). This work is currently being continued using SPOT 5 data (10 m pixel).

The conclusion from these studies is that ALS data provide a very accurate data source for prediction of forest near the tree line ecotone, and that ALS data improve satellite data based vegetation classifications. In addition, the DEM obtained from ALS data is also likely to be a good baseline for future tree line monitoring with 3D digital photogrammetry.

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Mapping the Length of the snow free seasons 2000-2010 in Northern Fennoscandia using MODIS data

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We present a map over the length of the snow free season over northern fennoscandia for the period 2000-2011 with 500 m spatial resolution. The map is based on an eleven-year data set with snow cover area fraction data from the two northernmost counties in Norway, Troms and Finnmark, and the northernmost areas in Finland and Sweden. The data were derived from the daily 500 m standard snow product (MOD1A10) from the MODIS sensor. We used multitemporal interpolation to eliminate clouds and a cloud free time series of daily snow cover fraction maps were processed. This result has subsequently been used to derive the first and last snow free day for each year for the entire study area. This result is validated against observations from 40 meteorological stations in the study area. The correlation is impressively good for almost all stations and all springs in the period 2000 to 2010, but the data from the falls are much more susceptible to winter darkness and cloud coverage resulting in much poorer correlation.

As a final result we present the average length of the snow free season for the region, by calculating the length of the snow free season for each year per pixel, and averaging over the period. This result has been compared to a variety of vegetation maps, phenolocial maps and climatological maps over the region to assess the validity of the product. The map displays striking features showing climatological differences at a scale that is favorable for interpretations of ecological features caused by local topography, coastal-continental variability etc.

Hyperspectral Arctic VEGetation Indices

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The YAMAL2011-expedition of the teams from the Earth Cryosphere Institute Siberian Branch of Russian Academy of Sciences (ECI SB RAS), RU, and the Alfred Wegener Institute for Polar and Marine Research (AWI), DE, took place during the period from August to September 2011. This expedition was part of the AWI-project 'hyperspectral Arctic VEGetation Indices' (hy-Arc-VEG), which is a component of the Environmental Mapping and Analysis Program (EnMAP), a German hyperspectral space mission with an expected launch date in 2015. Hy-Arc-VEG focuses on spectro-radiometrical field measurements of tundra landscapes to technically explore the potential of multispectral to hyperspectral satellite data for applications in the low-growing arctic tundra. Representative ground data need to come from well-described sites of a homogenous surface type. Since 2007, the NASA Yamal Land Cover/Land Use Change (NASA Yamal-LCLUC) team has established field sites in northwestern Siberia (Yamal Peninsula) to sample homogenous surface types that are representative for coarse-scale remote sensing applications. The ECI had established the Circumpolar Active Layer Monitoring (CALM) site at Vaskiny Dachi on the Yamal in the early 1990s. Vaskiny Dachi has been revisited every year for late-summer measurements of active layer depth and other system properties. The sites on the Yamal Peninsula represent a range of tundra landscapes with varying moisture regimes and vegetation structures.

For the Yamal2011-expedition, Yamal-LCLUC sites were revisited in August 2011: two at Laboravaya, southern Yamal, close to the Polar Ural Mountains, and three at Vaskiny Dachi, central Yamal, and along with the ECI CALM site at Vaskiny Dachi. New measurement plots were established along a 1.5 km transect (Tr11) crossing different permafrost regimes and vegetation communities.

With respect to spectro-radiometry, the main research goals of the Yamal2011 investigations are:

(i) remote sensing algorithms for spectral narrow-band and broad-band vegetation indices (VI): Normalized Differenced Vegetation Indices (NDVI), Leaf Area Index (LAI), fraction of Absorbed Photosynthetically Active Radiation (fAPAR). The results on NDVI-tundra,

fAPAR-tundra, LAI-tundra will be incorporated into the PAGE21 project (Changing permafrost in the Arctic and its global effects in the 21st century, www.page21.eu);

(ii) anisotropy studies on spectral reflectances using the in-house (AWI) developed portable field spectro-goniometer (EyeSight).

The spectro-radiometrical multi-zenith, multi-azimuth measurements simulate the viewing geometries of wide-angle looking satellite sensors such as AVHRR, MODIS, MERIS, or sensors with technical side-looking possibilities such as the EnMAP sensor.

The first results of the field measurements and the analyses of vegetation indices are presented and discussed.

Comparison of active microwave and optical imagery over the Yamal Peninsula as a validation technique for radar lake classification

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The Yamal Peninsula in northwestern Siberia is a typical permafrost thaw lake landscape. It is a ground-ice-rich, poorly drained lowland that covers an area of approx. 122 000 square km. There are numerous streams and rivers that meander through this Arctic landscape.

Active microwave imagery has become an important method for monitoring the hydrosphere. For this study the European Space Agency's ENVISAT Advanced Synthetic Aperture Radar (ASAR) instrument, operating in wide swath (WS) mode is used to classify water bodies on the Yamal Peninsula. Many thaw lakes lie below ASAR WS's spatial resolution of 150 m. The applicability of using this radar sensor for lake classification is investigated.

The ability of ASAR WS imagery to detect lakes is tested using simultaneously acquired optical imagery from the Japan Aerospace Exploration Agency's ALOS Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) instrument. PRISM data have a much higher spatial resolution, with a pixel spacing of 2.5 m.

This comparison shows that ASAR WS datasets are a useful tool in monitoring Arctic thaw lakes, despite their rather coarse resolution.

Remote sensing and multi-scale integration for investigating 'Changing permafrost in the Arctic and its global effects in the 21st century – PAGE21'

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PAGE21 (ENV.2011.1.1.3-1, www.page21.eu) aims to understand and quantify the vulnerability of permafrost environments to a changing global climate, and to investigate the feedback mechanisms associated with increasing greenhouse gas emissions from permafrost zones. This research will make use of a unique set of Arctic permafrost investigations performed at stations that span the full range of Arctic bioclimatic zones. As part of the project remotely sensed data will be integrated with in situ measurements for improved process understanding and model validation. A wide range of Earth Observation datasets at model scale are available for this purpose, but there is a lack of representation of heterogeneity and dynamics, in particular. This needs to be addressed, as well as the actual suitability of the available data, by incorporating state-of-the-art approaches regarding surface cover distribution and the dynamics of biogeophysical properties, for all observation sites and across all scales.

Landsurface temperature (LSCE, LGGE)

Microwave radiometers will be used to assess land surface temperature diurnal variations at regional scale (25km) for all the Arctic region. Thermal infrared measurements will helped to downscale the data to the kilometric scale for all the observations sites. The downscaling procedure will use a priori land surface temperatures estimated with a land surface model, to constrain the inversion process. The methodology under development at LSCE, will be presented.

Landsurface Hydrology (TUW)

ERS and Metop scatterometer derived soil moisture (25-50 km resolution) will be combined with ENVISAT ASAR data (150 m - 1 km resolution), and Sentinel 1 data if it becomes available, for periods with unfrozen conditions for across scale assessment of land surface hydrology. The potential of data from these active microwave sensors for high latitude land surface characterization will be discussed.

Phenology (UPD)

A remote sensing methodology has been developed to measure the timing of ecosystem green-up, closely related to the timing of leaf appearance, based on medium spatial resolution optical sensors (NOAA/AVHRR and SPOT/VGT). This methodology allows us to analyse the inter-annual variations of this key functionnal trait of arctic ecosystems. The comparison of these time series with those obtained with active and passive microwave remote sensing, that detects timing of key events such as the freezing or defreezing of soil, snowmelt and snowfalls, will permit an assessment of artic ecosytems functionning at scales that are not accessible by ground observations only. Moreover, the analysis will be completed by a comparison by the remote sensing products of surface temperature.

NDVI_tundra, fAPAR_tundra, LAI_tundra (AWI)

Remote sensing algorithms for the Normalized Differenced Vegetation Indices (NDVI), Leaf Area Index (LAI), fraction of Absorbed Photosynthetically Active Radiation (fAPAR) all use the NIR spectral bands. Due to low NIR reflectances from low-growing biomes, NDVI, LAI and fAPAR values for tundra fall into low ranges. Within the further preprocessing for models (permafrost/climate) the low values are falsely parametrised as large areal contributions of barren soil. Spectro-radiometrical field investigations at various Arcitc sites representing a range of tundra landscapes with varying moisture regimes and vegetation structures shall provide ranges for fAPAR_tundra, LAI_tundra.

Application of the remote-sensing data to permafrost mapping: a case study in Central Yamal

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Permafrost mapping and modeling is based on the understanding of the main controls affecting permafrost parameters: ground temperature, active-layer thickness, cryogenic processes. In the Tundra zone, remote sensing can provide necessary information on spatial distribution of surficial parameters represented by vegetation type and coverage. Vegetation serves on one hand as an insulation ground cover (moss, lichens), and as an entrapment for snow (shrubs), and on the other hand vegetation indicates drainage conditions (sedges for wet environments, lichens for dry ones, mosses and shrubs for mesic).

A case study was undertaken at central Yamal at the research station Vaskiny Dachi. In summer 2011 a 1.5 km long transect crossing main geomorphologic units of central Yamal was established and subject to multipurpose field study. Detailed description of vegetation and numeric parameters characterizing tundra complexes was followed by active-layer measurements. Main complexes affecting permafrost were subdivided into main classes, such as barren surfaces, shrub-dominating, moss-dominating and sedge-dominating communities.
Thus there exists detailed ground data (Brown-Blanquet, spectro-radiometry, Munsell colour value for vegetation) to guide the processing and the interpretation of remote-sensing data. The optical satellite data base is a high-spatial resolution GeoEye-1 acquisition with 0.5 m ground sampling distance acquired at the 15th August in 2009 (NGA license, University Alaska Fairbanks, NASA LCLUC Yamal).

Spectral analyses were performed to extract surface classes: surface waters, barren surface, shrub-dominant, moss-dominant and sedge-dominant communities. Spectral discrimination of surface waters was done using a threshold value in the near infrared band 4. The barren surface was discriminated using the NDVI.

Various spectral analyses were tested to separate shrubs-dominated, moss-dominated and sedge-dominated surfaces. Processed were 4 Principal Component (PC) bands, including masking of surface waters. The lower PC bands contain the subordinate information that can often not be extracted using standard classification methods. PC bands 2 and 3 were interpreted to contain information on 'greenness' and 'moisture and structure', respectively. At this stage, the shrubs were manually digitized guided by the structure information in PC band 3.

The 'greenness' can also analytically be calculated as chlorophyll absorption depth using the GeoEye bands green (Band 2), red (Band 3) and near infrared (Band 4). The spatial pattern of the calculated chlorophyll absorption depth correlates with the spatial pattern of PC band 2. Thus, the assignment of the sedge-dominance to PC band 2 proves to be acceptable and automatically extractable.

The sedge-dominated areas exhibit higher maximal GeoEye-NDVI values compared to shrub-dominated. The lower NDVI range for sedge-dominated areas overlaps with the NDVI range for shrubs. Therefore, the NDVI is not a clear proxy for discrimination of shrubs and sedges. The late-summer state of shrub-dominated surfaces exhibit more reddish-brownish colours, whereas sedge-dominated areas inherent the green colour range.

Future effort will be directed to compilation of the Vaskiny Dachi permafrost map based on the correlation of ground temperature and active layer depth with the surface classes.

The relationship between phytomass, NDVI and vegetation communities on Svalbard, Arctic Norway.

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Several studies have shown the relationship between vegetation communities, vegetation density and different vegetation indexes extracted from satellite data. The vegetation density in Arctic is highly related to temperature. At lower scales elements like surface material, snow cover, hydrology and anthropogenic effects (geese, reindeer) are important determinants in constituting the different community types. The extent and occurrence of different vegetation communities are most often expressed through vegetation maps. On Svalbard a vegetation map, covering the entire archipelago, has recently been developed. The map is differentiated into 18 map units showing large areas of non- to sparsely vegetated ground. The most favourable vegetation is seen as productive marshes and moss tundra communities in the lowland.

Various mathematical combinations of spectral channels in satellite images have been applied as sensitive indicators of the presence and condition of green vegetation. Today the Normalised Difference Vegetation Index (NDVI) is mostly used to display this information. NDVI is an indicator of the density of chlorophyll and leaf tissue calculated from the red and near infrared bands: NDVI = (NIR-RED) / (NIR+RED). In this equation NIR represents the band 4 (0.76-0.90 μm) of Landsat 5 and 7 and RED the corresponding band 3 (0.63-0.69 μm). NDVI gives values between -1 to + 1 where vegetated areas in general yield high positive values, while non-vegetated ground is found on the negative side.

The overall aim of the present study was to test the correlation between NDVI and field-recorded phytomass data on Svalbard, Arctic Norway. During the field study the clip-harvest method was conducted on 104 plot sites in the areas of Adventdalen and at Kapp Linné. Every sites recorded was geo-located using GPS. In the image processing part, the available Landsat 7/ETM+ image from 17th of August 2000, was converted into an NDVI-image. From this image NDVI data at the plot sites were recorded. The NDVI data were recorded inside a circle of 100 m around the measurement centre. The correspondence between the point-recorded phytomass and correspondent NDVI data show a correlation of R=0.824. Comparable comparison of community based NDVI and recorded phytomass show a correlation of R=0.850. The recorded correlation of community based NDVI and the plant phytomass were used to estimate the total plant phytomass for the entire Nordenskjöld peninsula, including 12 subareas. In the discrimination of the peninsula six of the subareas are located in the lowland, the remaining six in upland regions. The overall phytomass for the entire Nordenskjöld peninsula (3972 km^2) is estimated to 604,4 tonn*103 giving an average amount of 0.152 g/m2. Correspondent values for lowland and upland areas are 0.239 g/m^2 and 0.094 g/m^2, respectively. The most favourable lowland region is estimated for the areas of Reindalen and Berzeliusdalen with a phytomass amount of 0.288 g/m^2.

A Robust, Cross Validation Classification Method (RCM) for Improved Mapping Accuracy and Confidence Metrics

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A modified approach to existing classification procedures, the Robust Classification Method (RCM), is introduced. This algorithm is based on a randomized and repeated sampling of a training dataset in concert with traditional cross-validation of the classification results. A series of predictions (classified maps) and associated uncertainty maps and statistics are produced. The algorithm and associated outputs are discussed and a case study dealing with the classification of surficial materials in an area in Nunavut (NTS mapsheet 66A), Canada using RCM, is presented. However, this algorithm is applicable to any classification application including vegetation, land use, agriculture as well as geological mapping of bedrock and surficial materials.

The Robust Classification Method is especially useful for assessing the effects of spectral and spatial variability in the classification process. Specifically, this method provides a majority classification and variability map and confusion statistics to bracket uncertainty in the classification process with respect to statistical (spectral) variability in the training dataset used to perform the classification as well as identifying areas that show spatial variability in classification.

Anthropogenic and natural land use and land cover changes in tundra environments detected from satellite image time series on Yamal Peninsula, Russia.

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Petroleum production activity causes a rapid land use and land cover changes in the Russian Arctic. At the same time occur natural land cover changes e.g. cryogenic landslides, changes in hydrology (disappearing lakes). We have studied land use and land cover changes in and around the Bovanenkovo gas field located on the Central Yamal peninsula. The gas field was discovered in late 1960's and large scale building of infrastructure started in 1988. Almost at the same time there was a significant peak in cryogenic landslides (1989-1990). Several hundred landslides occurred in the surrounding area. Both anthropogenic and natural changes were investigated with satellite imagery time series (Landsat MSS/TM/ETM7, SPOT, Terra ASTER VNIR, Quickbird-2 and GeoEye). It is noticeable that both anthropogenic and natural changes studied are difficult to differentiate from each other especially from coarser resolution imagery (e.g Landsat). Fresh landslide surfaces reflect light a level similar to other bare surfaces and differentiating fresh landslides from sand, bare soil patches, river and lake banks and anthropogenic disturbances (quarries, yards, etc,) is a demanding task. Field data for this research was collected from several years and sites. The earliest and most detailed data are from 1993 from a large landslide complex close to Vasckiny Dachy camp. More recent data were collected in 2004 and 2005, 2011.

Landsat provided the most comprehensive time series covering the region studied (Landsat MSS 1985, TM 1988, TM 1999, ETM 2000, ETM 2009, TM 2011). Other higher resolution imagery was used to check and verify the Landsat-based interpretations. NDVI, image classification and visual interpretations were used in the study of the land cover and land use changes. Changes in NDVI show clearly when the anthropogenic disturbance begins in 1988, and also how construction of the road network decreases off-road vehicle impacts. In Landsat images from 2000 and 2011 it can be discernec that many areas originally disturbed in 1988 have been revegetated and NDVI values have increased. Cryogenic landslides that occurred in 1989 are most distinguishable in 1993 and 1998 SPOT images, but are still detectable in 1999/2001 Landsat imagery. In the most recent Landsat image from 2011, partly revegetated landslides are already difficult to identify. This study demonstrates that rather small scale anthropogenic land use and natural land cover changes can be observed even from relatively coarse scale resolution imagery. Although the "timing" of imagery used is important in identifying the studied small-scale changes, within 10 years such site can already regenerate to the point where they become difficult to distinguish.

Use of Airborne LIDAR for Research Carrying Out in the Interest of Fisheries Oceanography Information Ensuring

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At present requirements on truth and accuracy rough data in the interests of fisheries oceanography information ensuring are increased. Also it is very important to get complex data from great sea area for short time. One way of that, in the first for above is using of airborne remote sensing data from different type remote sensing equipments, and next is using new type equipments. Therefore during last several years PINRO uses for fisheries oceanography information ensuring new remote sensing methods, which is base on using of LIDAR systems. This system is installed and operated onboard of two engine research aircraft "Antonov-26" (An-26), named "Arktika" (in English it is "Arctic").

Ocean air remote sensing LIDAR methods are based on analyze of intensity, spectral, polarization, angular and temporal characteristics of reflected LIDAR echo-signal, which appears to sound of water subsurface layers by short strong laser impulse.

One of optic electromagnetic radiation range peculiarities is capacity to extend at the water environment and air that allow to LIDAR to carry out of water sounding through line between air and water, penetrating at the sea closely surface layer. Besides, if laser sounding impulse has linear polarization and has two receiving and recording channels, which are intended for recording of two echo-signal components with reciprocally orthogonal polarization has possibility to make identification of displayed object in echo-signal analyze.

Indicated task was realized for polarization aviation LIDAR (PAL-1) with success and effectiveness. It was designed and manufactured by "MULTITEKH" company from S.-Petersburg. PAL-1 has not analogues in Russia in modern stage for carrying out of air research in the interests of fisheries oceanography. PAL-1 is operates by PINRO specialist during last years.

The main PAL-1 specifications are following:
- electromagnetic wavelength – 532 nm;
- pulse duration – 12,5 ns;
- pulse energy – 120 MJ;
- pulse frequency – 1-40 Hz;
- optical receiver diameter – 10 cm;
- patch on sea surface – 1m;
- polarization vector – normal and cross.

Information obtained by PAL-1 are processed in two stages:

- onboard research aircraft, in real time, with aid of special LIDAR programme;

- after the flight (so named data post-processing) when more detailed analysis is made and data are interpreted as well as new algorithms and software are evaluated.

During this time PAL-1 was highly successfully, reliably, effectively and qualitatively used in remote sensing detection of upper sea water layers vertical profiles and optical characteristics to depth of natural transparency for difference water area, detection of fish aggregations, and first mackerel, and also in chlorophyll fluorescence pigments recording from board of research aircraft.

Research of the White/Barents Seas Harp Seal Population on Whelping Patches with Use of Multispectral Air Surveys

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PINRO has a long historical experience for airborne research by study of the White /Barents Seas harp seal population on whelping patches with purpose of pup production abundance assessment. The first research this direction was carried out more than 85 years ago. From this time to today gone way from simple visual observations from aircraft to using of modern methods and technologies where apply remote sensing equipments which work in optical and infrared (IR) ranges of electromagnetic wavelengths. This case the main research biological object is only one and it is pups of the White/Barents Seas harp seal population. This reason this modern technology for study above biological object was named as multispectral.

During fifteen last years multistectral aerial surveys carry out onboard two engines aircraft Antonov-26 (An-26) named "Arktika" (in English it is "Arctic"). Onboard this aircraft installed and operated following remote sensing equipment:

- standard digital photo – and video cameras («Nikon D1X» and "Panasonic", accordingly),
- IR-scanner "Malakhit" which was worked, created and adopted for considered aerial research specially.

Airborne research on study of the White/Barents Seas harp seal population pup production abundance on base of knowledge of harp seal biology carry out during March first half but no later than March 22. The main area of research is the White Sea and adjacent water of the Barents Sea, the first south-east part. All research flights carry out along basic transects which are oriented along longitudes with distance between its no more than 10 km from flight altitude no less than 200 m, standard is 250-300 m. Each research flight transect begins and finishes on ice edge or coastal line.

When considered research flights are finished then starts optical and IR-images special processing and analyze where use approaches and methods which were worked and created by PINRO. After that makes special calculation on total pup production abundance assessment which use in future for calculation of the White/Barents Seas harp seal population stock size.

For example, at present the White/Barents Seas harp seal stock has stable low level values, in 2005 it was 122 700, in 2008 - 123 100,in 2009 - 156 600, in 2010 and 2011 - 163032. Between 2005 – 2008 during two years airborne research on study of the White Sea harp seal population pup production abundance under above main principles did not carry out on logistical reasons. In 2005 was recorded the lowest modern level of pup production abundance. Under carried out additional and special research the main reason that was climatic changes in the Russian Arctic west part. Here was recorded warmer that cased decrease of ice cover area and ice season duration in comparing with end of 1990-s years and 2000-s beginning when was recorded the White Sea harp seal population pup production modern maximum.

Paleo-landslides in the Suasselkä fault-zone, Finnish Lapland, derived from LiDAR data

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Northern Fennoscandia has experienced high-magnitude (>M 7) neotectonic fault deformations that are attributable to intra-plate glacio-isostatic rebound. Postglacial faults and paleo-landslides, portraying post-Younger Dryas neotectonic fault-instability, are often difficult to recognize beneath forest canopies. We addressed this problem using LiDAR (Light Detection And Ranging) to recognize landslides in the vicinity of the Suasselkä fault-zone in Kittilä-Levi area, western Finnish Lapland. In field, the slide scars and sediments were surveyed with VRS-GPS (Virtual Reference Station Global Positioning System) and azimuthal EM-measurements of the soil electrical conductivity. LiDAR-data (by the National Land Survey of Finland) was obtained in 2009 with a Leica ALS50-II laser scanner from a flight altitude of 2000 m. The data was interpolated to 2 by 2 m grid, and the standard slope filters, supplied with Erdas/ER Mapper 7.2, were used to compute the slopes. The normalized results allowed the slope measurements regardless of direction, and slope angle within the range from 15 to 30 degrees correlated best with the recognized landslides.

We found, with 15-cm-resolution LiDAR-data, a total of four sets of previously unrecognized paleo-landslides to indicate neotectonic fault-instability in the Kittilä-Levi area. The size distribution of the paleo-landslides varied up to 50m in width, up to 500 m in length and from 10 to 20 m in the height of the back-walls of the slides. A previously unrecognized (tentatively fault) scarp, 5 m in height and associated with paleo-landslide, was found west of the Kittilä village. The slide debris was similar in texture to local tills, yet the sedimentary anisotropy was incoherent to the ice-flow (morphological) stages recognized through LiDAR. The ^{14}C-age determination of landslide-buried woody remnants of birch (*Betula* ssp.) yielded cal. 9,730 yr BP. Evidently the Early Holocene landslides, triggered by seismic tremors, were associated with inter-annual soil saturation, yet snowmelt had been the major contributor to sediment instability. We contend that LIDAR-detection of paleo-landslides is an important asset for regional mapping of former fault-instability, particularly for the site selection of nuclear power plants and radioactive waste disposal, in glaciated terrains of Fennoscandia.

Image and data processing of airborne geophysics for geological mapping and mineral exploration: Case study from the Wopmay Orogen, N.T., Canada

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Standard optical imagery relies on unobstructed outcrop for lithological and structural interpretation; however a large portion of the Canadian sub-arctic does not provide these ideal conditions. Such is the case for the Wopmay orogen, a Paleoproterozoic orogenic belt that is host to regional and local-scale fault configurations, multiple generations of dyke swarms, and various mineral occurrences. The Wopmay orogen is located within the tree-line, which results in much of the orogen being covered by vegetation in addition to lakes and glacial overburden. The outcrop that is available is covered by extensive lichen which mitigates standard optical imaging. In this case, alternative remotely sensed data that does not rely on surficial imaging, but rather on sub-surface resolution is required. Aeromagnetic survey data allows for lithology and structure identification through physical rock property contrasts (i.e. magnetic susceptibility) regardless of outcrop availability. When aeromagnetic data is used in conjunction with existing geoscientific data (e.g. radiometrics, topography, Landsat, geology maps) comprehensive products are generated known, this is Remote Predictive Mapping (RPM). The primary objective of an RPM product is to help expedite future field work by cutting down on what is typically costly, time-consuming, and laborious work. This is particularly true in remote locations such as the Canadian sub-arctic and arctic. Additionally, the RPM outputs aid in Mineral Resource Assessments (MRA) where mineral vectors are identified and may lead to associated mineral occurrences. These mineral occurrences are often linked to structures such as faults, fractures and dykes; therefore identification and extraction of these features is also critical for resource exploration.

Our RPM method involves the computation of surficial curvature of the aeromagnetic data in grid form to identify physical property contrasts (i.e. lithological contacts) and continuous localized lows (troughs) or highs (ridges) (i.e. lineaments). These lineaments may represent faults that have undergone alteration (i.e. magnetite depletion) or may be normally-magnetized dykes. From the Wopmay orogen aeromagnetic data, multiple lineament populations are identified via curvature analysis that represent the Mackenzie dyke swarm, mafic dykes, the Wopmay fault zone, and multi-scale faulting. Analysis of these extracted

lineaments in conjunction with additional geoscientific data aid in corroborating results and to identify potential mineralized zones. At the same time as the aeromagnetic survey, radiometric data was acquired and helps in the identification of rocks that may have undergone alteration (e.g. potassium and uranium enrichment or depletion). However, radiometrics resolves only the top 30 cm and may not represent bedrock alone. Comparing the radiometric survey data with topography and Landsat imagery eliminates all radiometric anomalies associated with glacial till accumulation and water bodies. This is accomplished by draping both the radiometric and Landsat imagery overtop of the 3D topographic surface.

Final RPM products include a probability map for mineral exploration and a geological map indicating the locations of lithological contacts and structure. The former product shows reliability when compared with pre-existing mineral occurrence databases while the latter product provides an interpretation over inaccessible areas or those that may not be imaged by standard remote sensing techniques.

A Multi-Sensor Approach for Synthesizing High Resolution Daily Snow Covered Area

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Arctic and alpine seasonal snow covers typically exhibit a high degree of spatial and temporal variability, making remote sensing a key component of any successful snow cover monitoring strategy. The availability of 500 m spatial resolution daily snow covered area (SCA) maps derived from MODIS represents a major leap forward for snow cover monitoring. Many applications, however, require or would benefit from snow cover data available at a finer spatial resolution. The Landsat series of sensors has been acquiring imagery suitable for snow cover monitoring at 30 m spatial resolution since 1984, with hundreds of dates of imagery available for many areas of the world. The infrequent repeat interval for image acquisition for the Landsat sensors, however, is generally insufficient to capture the seasonal evolution of snow cover. While Landsat data alone is not well suited for SCA monitoring applications, in many areas, Landsat-derived SCA images from multiple years can be analyzed to map snow cover probability distribution patterns that remain fairly consistent across most or all years. Results from recent work indicate it may be possible to combine these Landsat-derived snow cover probability distribution patterns with coarser resolution daily fractional SCA images (such as those available from MODIS) to synthesize daily 30 m binary SCA. To date, the exploration of this downscaling approach has focused on temperate mountain regions of the western United States. In these regions, however, the approach has been demonstrated to be most successful in treeless regions where snow cover distribution patterns are controlled primarily by wind and solar radiation, as is typically the case across the Arctic. This suggests this approach should be well suited for application across Arctic regions wherever sufficient Landsat imagery is available.

Climate and grazing influences on circumpolar dynamics of arctic tundra vegetation, using NDVI-biomass relationships

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Numerous studies have evaluated the dynamics of arctic tundra vegetation throughout the past several decades, using remotely sensed proxies of vegetation, such as the Normalized Difference Vegetation Index (NDVI). While extremely useful, these coarse-scale satellite-derived measurements give us minimal information with regard to how these changes are being expressed on the ground, in terms of tundra structure and function. In this analysis, we used a strong regression model between NDVI and aboveground tundra phytomass, developed from extensive field-harvested measurements of vegetation biomass, to estimate the biomass dynamics of the circumpolar arctic tundra over the period of continuous satellite records (1982-2010).

The aboveground phytomass of circumpolar arctic tundra increased from 2.02 Pg (10^{15} g) in 1982 to 2.41 Pg in 2010 for a total increase of 0.40 Pg, a change of ~19.8 % over a 29-year time period (0.7 % y^{-1}). A relatively ubiquitous increase in tundra phytomass over time is observed circumpolarly, with isolated areas of phytomass decline in Beringian Alaska and the Kanin–Pechora region of western Eurasia (Fig. 1). With respect to the different tundra bioclimatic subzones, the three southernmost subzones (C, D, and E) exhibited extensive increases in aboveground phytomass (20.9 %, 25.6 %, and 20.6 % respectively), whereas the two northernmost subzones (A and B) showed substantially smaller increases (2.1 % and 6.4

% respectively). In addition, subzones C, D, and E comprise 87.5 % of the tundra landmass and 95.5 % of the initial tundra biomass in 1982; therefore the dynamics of the three southern subzones dominate the circumpolar tundra phytomass change. Whereas subzone D showed the greatest relative phytomass increase of 25.6 %, subzone E exhibited the greatest average absolute biomass increase of 96.1 g m^{-2} (3.4 g m^{-2} y^{-1}).

North America (Alaska and Canada) represents approximately 43.2 % of the tundra landmass and 45.4 % of the tundra aboveground biomass in 1982. Eurasian tundra is approximately 27.1 % of the tundra landmass, and 44.0 % of the tundra aboveground biomass. However, increases in tundra phytomass in North America over the past 29 years were generally greater than those in Eurasia. Alaskan tundra phytomass increased 7.8 %, and Canadian tundra phytomass increased 36.5 %, whereas tundra biomass in Russia increased 15.7 % (9.4 % in Western Siberia and 23.4 % in Eastern Siberia). The aboveground tundra phytomass is almost equally distributed between North America and Eurasia (0.91 Pg in North America and 0.89 Pg in Eurasia in 1982 compared to 1.07 Pg and 1.02 Pg respectively in 2010).

Based on modeling analysis using the ArcVeg tundra vegetation dynamics model, caribou and reindeer grazing have the capacity to reduce the tundra biomass response to climate change by greater than 50%. If the estimated vegetation change using remote sensing is the combined effects of climate dynamics and grazing, then the isolated vegetation response to climate changes could be double those observed.

The study of fragmented nature of Tundra landscape and its biomass using different resolution satellite images

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Northern latitudes have been predicted to experience faster and more extensive climatic changes than other regions. Thus, accurate land cover data of Arctic tundra is crucial, when different kinds of climate change related questions, like carbon storage and fluxes, are studied. During the past years very high resolution satellite images with a pixel size of less than ten meters have become available. As the tundra landscape structure is known to be very patchy when compared to other biomes, this kind of very high resolution images are needed, if the aim is to produce land cover classifications revealing the real land cover structure. Our work is part of the Carbo-North project (homepage: http://www.carbonorth.net/).

We present, how land cover classifications and biomass estimates of the study area located in north-Eastern European Russia can be produced using three satellite images (QuickBird, Aster and Landsat) of different spatial resolutions (2.4 m, 15 m and 30 m pixel size, respectively), and how obtained results differ. The Quickbird image was supervisedly classified using segmentation techniques, while the Aster and Landsat images were classified based on the classification of the fine resolution QuickBird image.

We analyzed the landscape fragmentation according to the different resolution classifications. The overall mean patch size in the Quickbird-, Aster-, and Landsat based land cover classifications were 871 m^2, 2141 m^2, and 7425 m^2, respectively. In the Quickbird classification the mean patch size of all tundra and peatland vegetation classes was smaller than one pixel of Landsat. Especially willow stands and fens are found in the landscape in so small or elongated patches that they can't realistically classified from coarser resolution images.

The land cover classifications of the three satellite images were additionally used to estimate the biomass of the study area using in field measured average biomass value for each class. These biomass estimates were subsequently compared to biomass estimates obtained through two other methods. The first of these was direct extrapolation of field data, where satellite images only were used for selecting the locations for field sampling. The second was to use the spectral reflectance of satellite images of the areas, for which the biomass was known, for constructing regression models, which then were used for calculating the biomass of every pixel in the satellite images. The estimated mean biomass of the area was similar according to the data collected in the field (741 g/m^2) and the land cover classifications of QuickBird (719 g/m^2) and Landsat (726 g/m^2), but the biomass of the Aster image was clearly lower (658 g/m2). The regression models gave 10-30% lower estimates of the above ground biomass and especially areas that should have been high in biomass (tree covered areas) were problematic. Aster was generally more problematic than Landsat both in the land cover classification and when predicting the biomass using the spectral reflectance, despite its higher spatial resolution. The land cover – and the biomass – of our study area vary in such fine-scale pattern that a lot of information is lost if only medium resolution satellite images are used.

An new medium resolution datasets of seasonal wetland dynamics from ENVISAT ASAR for northern Eurasia

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Active microwave satellite data can provide information on surface hydrology dynamics on local to global scale. Information includes inundation, surface wetness and status regarding frozen or thawed condition. The European platform ENVISAT carries an advanced SAR (ASAR) which provides C-band data in ScanSAR mode. These data can be used for update of inundation status with 150m spatial resolution at frequent intervals (several times per month depending on actual acquisitions). This complements regional to global wetland datasets with coarser scale (~25km). Smaller permanent and seasonal features as abundant in high latitudes and which are usually not captured with even medium resolution datasets can be identified. Continuation of C-band records is assured because of the future plans of the European Space Agency (ESA) with respect to the Sentinel series of satellites. The wavelength is between 5–6 cm, which means that even moderate wind action on the water surface can impede the specular reflection. Longer wavelengths such as L-band (>20 cm) would be therefore preferable for this application but their availability is limited at present, as well as in the near future. A further problem related to the use of C-band radar is the very limited penetration of the signal through emerging vegetation, for example along lake shores. The ENVISAT archive provides nevertheless a unique opportunity for medium resolution inundation dynamics mapping.

Land surface hydrology especially wetlands need to be considered for land ecosystem-atmosphere modeling at high latitudes. The suitability of active microwave data to help validate or constrain relevant models is investigated within the European Space Agency (ESA) funded project STSE ALANIS-Methane (Atmosphere-LANd Interactions Study, in collaboration with the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS), www.alanis-methane.info, lead by CEH Wallingford UK).

A freely available experimental dataset of inundation dynamics and saturated areas with 150 m resolution has been developed for the years 2007 and 2008. It covers the majority of Russian lowlands north of 55° latitude and is based on ENVISAT ASAR. The temporary open water information is provided for 10-day periods. Data availability is however constrained for many regions. Additional information is therefore provided for the number of available acquisitions during the 10-day period and the number of days since last update. Additional products are maximum extent of open water bodies and permanently high saturated areas.

These datasets complement the circumpolar free database (land surface temperature, surface soil moisture, land cover and terrain) which has been set up as part of the ESA DUE Permafrost project (www.ipf.tuwien.ac.at/permafrost).

Using a micro-UAV for ultra-high resolution multi-sensor observations of Antarctic moss beds

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This study is the first to use Unmanned Aerial Vehicles (UAVs) for mapping moss beds in Antarctica. Polar regions are experiencing rapid and severe climatic shifts with major changes in temperature, wind speed and UV-B radiation already observed in Antarctica. Since vegetation is isolated to the coastal fringe and climatic records only extend back 50 years, with limited spatial resolution, we urgently need new proxies to determine if coastal climate has changed over the past century. In a manner similar to trees, old growth mosses also preserve a climate record along their shoots. Mosses can therefore be used as sentinels to provide crucial information on how the Antarctic coastal climate has changed over past centuries.

The spatial scale of moss beds (tens of m^2) makes satellite imagery unsuitable for mapping their extent in sufficient detail. Recent developments in the use of unmanned aerial vehicles (UAVs) for remote sensing applications provide exciting new opportunities for ultra-high resolution mapping and monitoring of the environment. In this study, we developed a micro-UAV consisting of an auto-piloted multi-rotor helicopter carrying three different sensors: a 6-band multispectral sensor, a high resolution visible camera, and a thermal sensor for cost-effective, efficient, and ultra-high resolution mapping of moss beds in the Windmill Islands, Antarctica.

We developed a technique to extract an extremely dense 3D point cloud from overlapping UAV aerial photography and structure from motion (SfM) algorithms. The combination of SfM and patch-based multi-view stereo image vision algorithms and poisson surface reconstruction resulted in a 1 cm resolution digital terrain model (DTM). This detailed topographic information combined with narrow-band vegetation indices derived from the 6-band multispectral sensor and thermal imagery from the TIR instrument enabled the assessment of moss bed health and dynamics. This novel UAV system has allowed us to map different environmental characteristics of the moss beds at ultra-high resolution providing us with a better understanding of these fragile Antarctic ecosystems. The paper provides details on the different UAV instruments and the image processing framework resulting in DEMs, vegetation indices, and temperature data layers.

Finally, this paper presents the most recent development of a hyperspectral capable UAV. The integration of the mini-hyperspectral pushbroom scanner with an IMU/GPS sensor, data logger with accurate timestamping, and the UAV airframe will be presented and discussed. Preliminary results of this system will be presented in the context of moss bed health characterisation.

A review of hyperspectral remote sensing research for geological mapping and exploration of Canada's North

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Airborne hyperspectral methods have been shown to be highly effective for geological mapping and mineral exploration. However, the majority of research and development has occurred in areas of little to no vegetation cover, typical of hot, arid environments with abundant outcrop and/or regolith. There are fewer case-studies in the public domain that demonstrate the usefulness of hyperspectral remote sensing for the unique geographic and climatic conditions of Canada's North, exemplified by cold temperatures, minimal surface weathering, minimal vegetation cover, and variable lichen cover.

This talk summarizes hyperspectral research and development activities at Natural Resources Canada for geological mapping and exploration in Canada's North over the last 10 years. A number of case studies using a variety of airborne hyperspectral data are discussed covering themes such as spectral/lithological mapping, detection of alteration minerals associated with various mineral deposits including volcanic-massive sulphides and orogenic gold, the effect of lichen and other flora on spectra as well as the effect of weathering on spectra.

Hyperspectral imaging of boreal peatland biotopes along soil moisture and fertility gradients

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Spatial information on biotopes would be an asset for boreal peatland (i.e. mire) inventories. Further protection of peatland site types and monitoring changes in species diversity caused by artificial regulation of hydrology, atmospheric deposition, and global change would clearly benefit from nationwide spatially continuous mapping of peatland communities. We took a data-driven approach to explore the potential of airborne imaging spectroscopy (HyMap^{TM}) in determining plant associations of treeless northern boreal peatlands in Finland (65˚57'N, 24˚29'E). The objective was to produce an ecologically meaningful peatland classification on a class hierarchal level which would be as detailed as possible. Class hierarchy is dataset dependent, and thus re-evaluation for each future spaceborne hyperspectral dataset could be solved with the proposed analysis method for the most accurate mapping. The proper class level data was decided based on statistical approaches including canonical correspondence analysis, unsupervised classification and multivariate analysis of variance. Subsequently, fuzzy classification with support vector machines (SVM) was applied to map the classes in the spatial domain from airborne geo- and atmospherically corrected hyperspectal HyMap data. For *in situ* reference we conducted detailed sampling. Surface plant inventory, soil root zone bulk dielectric permittivity (ε), electrical conductivity (σ) and pH measurements were conducted. Analysis with constrained canonical correspondence ordination revealed that ε, σ ($p<0.01$) and pH ($p<0.001$) were significantly correlated with the ordination and were thus important drivers for vegetation composition. We found four ecologically meaningful biotopes to be distinguishable by their spectra: bog (*Sphagnum fuscum - Emperum nigrum - Rubus chamaemorus - S. angustifolium*), sedge fen (*Eriophorum vaginatum - S. lindenbergii*), eutrophic fen (*Carex lasiocarpa - Trichophorum cespitosum*) and swamp (*Comarum palustre - S. majus - Carex rostrata*). The highest overall efficiencies of prediction (overall accuracy 87.8 %, kappa 0.781) were calculated using only 10 % of the original training data. This confirms that low numbers of properly selected training sites from class boundaries would be appropriate for training of SVMs. The class specific assessment of accuracy with receiver operating characteristics curves also confirmed moderate-to-good successes of the approach with area under the curve values: 0.946 for bog, 0.951 for sedge fen and 0.999 for eutrophic fen. In the boreal peatlands clusters of spectrally separable cohesive communities existed but they gradually changed from one plant association to another. Thus fuzzy mapping from hyperspectral and possible complementary data (e.g. LiDAR, radar) with well performing SVMs could be justified in spatially continuous inventory and monitoring of boreal peatlands. Future research should focus on prolonging the ecological gradient to include the entire variability of peatlands by including drained peatlands and peatlands with tree cover in order to evaluate the usefulness of the approach at regional, landscape or national scales.

A dynamic and generic cloud computing model for environmental analysis using in-situ sensing data applied to glacier mass balance analyse (Mer de Glace, Chamonix; East Loven Glacier, Spitsberg)

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Analyzing landscape, its dynamics and environmental evolutions require regular data from the sites, specifically for glacier mass balanced in Spitsbergen and high mountain area.

Due to poor weather conditions including common heavy cloud cover at polar latitudes, and because of its cost, daily satellite imaging is not always accessible. Besides, fast events like flood or blanket of snow is ignored by satellite based studies, since the slowest sampling rate is unable to observe it. We complement satellite imagery with a set of ground based autonomous automated digital cameras which take 3 pictures a day. These pictures form a huge database. Each picture needs many processing to make it readable (geometry, atmospheric disturbance, modification of the shooting's parameters ...). Most of these in-situ constraints can be adjusted by computer.

At this time, the environment analysis is done by using specifics tools. These tools are not user friendly, and they do not allow mass processing. Each processing has to be done specifically for each group of data. There is a real need to provide a tool that can dynamically change the processing and also be as generic as possible to feet other needs. We propose to build a stand alone tool which can classify a large variety of phenomena avoiding as much as possible human operation.

Cloud computing is a set of resources, servers and applications, offered "as a service" and accessible from the network. Cloud computing provides several advantages like easiness of access, lightness of application, scalability ... Moreover large amount of data can be loaded in the cloud computing. Also, it gives the opportunity to add or remove functionalities fitting to the user's needs. Finally, it supports not only the increase of users connected to the application, but also the computing capacity according to the needs.

In order to classify the phenomena, several tasks have to be done. Different classes of picture's processing have been identified: dating, cropping, cleaning, projecting, categorizing.

Each task corresponds to several elementary jobs. The jobs match with specific complex algorithm fitting one particular constraint (electronic deficiency, meteorological perturbation, geometry variation ...). These jobs can be deployed as web services. The latter could be integrated in the cloud computing easily. All the processing have to be implemented as generic as possible.

As the image processing sequence is not set in advance, we have to provide a planner taking under consideration the processing. A planner is a process which allocates resources and schedules actions in an optimal way in order to achieve a goal, satisfying a set of constraints.

In the first part of our contribution, we can provide a static planner to apply the processing on the data and then we can analyze the different phenomena. Further, we can provide a dynamic planner, which will be able to choose the best workflow for each image to produce a workable image for classification. Each planner will use web services for each elementary task. Because of in-situ sensing growth, this model answer to real data processing.

Polarimetric analyses of dominant radar backscattering mechanisms for iceberg detection

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Iceberg detection in sea-ice covered waters using single polarization SAR is hampered by similarities between backscattering signatures of icebergs and sea ice deformation structures. Therefore, we investigated whether iceberg detection is more robust when polarimetric SAR images are used. From the science point of view, the advantage of such data is that they indicate the dominant backscattering mechanisms. For our study we have five RADARSAT-2 images available, recorded in the Bellingshausen and the southern Weddell Seas. Within the images, overall 683 icebergs of various sizes and 357 sea-ice regions of interest (ROIs), separated into three different sea ice classes, were identified. For icebergs and sea ice ROIs, the polarization ratio, the co-polarized phase difference and correlation coefficient, and entropy, anisotropy and alpha angle were calculated, compared and analyzed.

The co-polarization ratios of icebergs (σ_{VV}/σ_{HH}) are close to one, which can be explained by scattering from larger surface elements (modeled by Geometrical Optics) and/or volume scattering from spherical air inclusions in the ice. Only the ratio values of smooth sea ice differ significantly from the ones of icebergs. Icebergs reveal high depolarization ratios (σ_{HV}/σ_{HH} and σ_{VH}/σ_{VV}) and low correlation coefficients (ρ_{HHVV}), which is typical if multiple scattering occurs. The phase difference (ϕ_{HHVV}) of icebergs is significantly larger than zero (about +50°), which can be explained by different propagation velocities of horizontally and vertically polarized waves and double-bounce reflections in the ice volume. The phase difference (ranging from -180° to 180°) of sea ice is around zero or shifted to slightly negative differences (max. -25°). The anisotropy is useful for the discrimination of scattering processes for which the entropy is >0.7. Since only a small number of our observations fulfill this criterion, we used an unsupervised entropy-alpha decomposition for the determination of the major backscattering mechanisms. Icebergs are dominated by dipole scattering in both areas of investigation. Sea ice signatures vary between the two areas because of differences in the ice type distribution. In the Bellingshausen Sea, the sea ice backscattering is dominated by scattering from rougher surfaces but includes also contributions from the volume. In the Weddell Sea region, the backscattering of sea ice is characterized by surface scattering. The signatures are influenced by the radar incidence angle. The Weddell Sea images are recorded at lower incidence angles (18-20°), at which surface scattering is more distinct. In the Bellingshausen Sea, the incidence angles are 47.5 to 48.7° and 40.2 to 41.6°, at which volume scattering contributions cannot be neglected. The analyses show that the incidence angle impact on the polarimetric parameters is larger for sea ice than for icebergs, and that lower incidence angles are preferable for iceberg detection. The separation of deformed sea ice and icebergs is improved if the phase difference, entropy, and alpha parameters are used as additional classifiers besides radar intensity.

The climatic fluctuation effects of last 30-years to cryolithozone ecosystems in Russian Arctic. Remote sensing approaches

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The analyses of prepared meteorogical database for project region demonstrate presence expressed trends of average annual temperature value growth. The temporal series of collected satellite images NOAA-AVHRR (1982-2006 years period, 15 days periodicity), SPOT-Vegetation (1998-2004 years, 10 days periodicity), Terra-MODIS (2000-2009 years, 16 days periodicity), Landsat (1973-2010 years, episodically) were used for selection of statistically significant trends of natural positive (the mountain forests of national park «Ugyd-Va» and some areas of Bolshezemelskaja tundra and Taymyr peninsula) and negative (the territory of old age plain forests of Pechora-Ilych state reserve) dynamics of vegetation production. Some areas of North-Europe Russia (the western part of Bolshezemelskaja tundra and Yugorsky Peninsula) were investigated by geobotanical and aerovisual methods. The increasing of vegetation community's biomass was mainly related with growing amount and biomass of shrubs (willows and Betula nana) in areas with constant permafrost soils. For the territory of mountain forests of Subpolar Ural protected areas the main natural trends of forest density were related with increasing of crown density in ecoton zone with rare Larix (SMA-method of analysis). The average increasing intensity is near 1-2% per year on gently sloping mountains slopes. The forest density was more stable in plain part of area and mountain conifer forests.

The satellite images analysis showed the response of cryolitezone in the North-Europe Russia to climate changes. The maximum observed changes for thermokarst lakes were related with drainage of lakes at the area of discontinue permafrost zone. Near 80% of changes at this zone were fixed for period 1973-1988 years. The area of continues permafrost zone was most stable for changes until 1988 year. The main changes of lakes were observed for this zone in period of 1988-2002 years. The changes intensity was increased in direction to the south border of discontinues cryolitezone and for all permafrost area after 2002 year. This changes can be associated with climatic warming noted after 70-s.

On basis of comparable analyses of time-series satellite data (Terra-MODIS (2000-2011 years, 16 days periodicity), Landsat (1973-2010 years, episodically) and QuickBird scene (2007 year)) was developed technology for quantitative estimation of features of vegetation in model area (carbon accumulation, projective chlorophyll content, biomass, productivity). Estimation of seasonal changes of parameters of native vegetation for years of first decade of 2000 demonstrate more stable level of variations for area then early supposed. Main part of climatic caused changes concentrated in permafrost zone in few regions (South of Yamal, Gydanskii state reserve, East of Bolshezemelskaja tundra (disjunctive) and Kolyma river basin). The trend of increasing of aboveground green biomass in this regions is near 7-30 kgC*ha per year $^{-1}$. In boreal area and in Pechora-Ilych reserve features was more stable. The model of modern dynamic of aboveground vegetation biomass is developed (Fig 1).
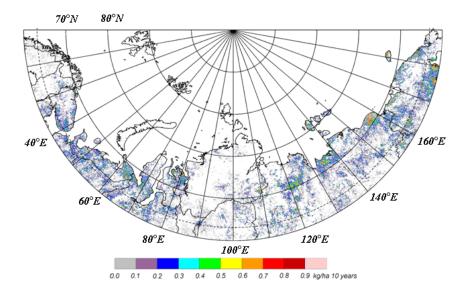
Fig 1. The model of intensity of projective chlorophyll dynamic changes in vegetation for North Eurasia for 2000-2011. The MODIS satellite data.

Investigating topographic normalization, satellite data source and classification method for alpine vegetation mapping in a sub-arctic area of Sweden

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There is a need for updated and detailed vegetation maps over Sweden's mountain areas. While optical satellite data are useful for mapping remote areas, the mapping of alpine vegetation presents several challenges. One challenge is correction of satellite data for illumination differences influenced by topography and solar angles, which can be pronounced at high latitudes. Another challenge is the accurate mapping of detailed vegetation classes that have a high degree of spectral similarity and occur in complex spatial mosaics.

The *c*-correction (Teillet *et al*., 1982) is a commonly used topographic normalization method for alpine vegetation areas. Deriving an accurate value of the empirical parameter "*c*" is important for achieving correct image normalization and is best derived using a stratified sample with optimal allocation. Without this sampling strategy, there is a risk of incorrectly normalizing the satellite image, leading to lower classification accuracy.

Sixteen alpine and subalpine land cover classes were classified, including grass heath, dry heath, mesic heath, short alpine meadow, tall alpine meadow, willow, bare rock, snow bed vegetation, and mountain birch. A photo-interpretation of 2,300 multiple-scale plots showed that an average of 1.4 vegetation types occurred in 10 m radius plots, while 1.9 types occurred in 20 m radius plots, further confirming the heterogeneous nature of the landscape. These photo-interpreted plots, based on a systematic sample, were used as training data for two classification methods (Quadratic Discriminant Analysis and Random Forest), and applied to SPOT 5 and Landsat 5 TM satellite data which have pixel sizes of 10 and 25 m, respectively. The images were topographically normalized using the previously mentioned *c*-correction method. A 50 m cell size DEM was used to include elevation and elevation derivatives (e.g., slope, aspect and a topographic wetness index) as ancillary data in the classification. The highest overall classification accuracy for the alpine vegetation classes was obtained using a random forest classification of SPOT 5 and elevation data (72.9%). When SPOT's spectral data were classified without including the ancillary elevation data, the accuracy decreased by 8.9%. Using the same training data and a random forest classification, Landsat TM combined with elevation data resulted in 62.7% overall accuracy. Classifications using a subjectively collected training data set were also run, resulting in only somewhat lower classification accuracy (69.9% for SPOT 5 and 56.5% for Landsat) than when training data were derived from the larger, systematic sample of training data. When assessing accuracy of more generalized alpine and subalpine classes (bare rock, alpine heath, snow bed, mire, mountain birch, and water) from SPOT data, an overall classification accuracy of 87.7% was obtained.

To examine the effect of training data set size, the systematic sample of training data was reduced, with results showing that accuracy decreased with training data set size for classifications from SPOT and Landsat TM data. By comparing Transformed Divergence values for different size training data sets, it was seen that between 40 to 60 training samples per class were sufficient for stable representation of the spectral variation in a four-band SPOT image.

The Barents Sea Marine Environment Air-Space Monitoring in Hydrocarbon Raw Materials Extraction and its Transportation

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Many years practice of several countries which carry out industrial extraction of hydrocarbon raw materials on sea shelf shows that organization and carrying out of marine environment reliable and qualitatively regular monitoring is one of important element it. This circumstance has particularly importance when the same large scale works carry out in marine area which has some specific ecosystem peculiarities similar the Barents Sea including very great important for fisheries.

Carried out researches, accumulated own experience and knowledge with other countries accounting experiences allow to tell that largest effect from regular monitoring of marine environment in above works can be got in case of special service regional creation. This service would created on base one or several scientific regional organization which have great experience on preparing and carrying out of air-space sea monitoring. This monitoring allows to have very good possibility to operative display and record any emergency situations, react to its origin, and then quickly, reliably and qualitatively remove its.

This marine environmental air-space monitoring can include following base elements.

1. Satellite monitoring (carries out every day), and it include following:

- using satellites which have radar system. This system ensures effective, reliable and qualitative discovering and recording of any types organic pollutions including oil flood and films independent on clouds, fogs, mist, precipitations and other atmospheric phenomena availability. At present time this task can be solved with using of satellites ENVISAT, RADARSAT, ERS-2;

- using satellites which have optical multicpectral systems with very high special resolution. Now a lot of the same satellites fly in the space, and therefore its enumeration has not meaning. However here is need to note some limitation using these satellites which have great significance for the Barents Sea, it is considerable dependence on atmospheric conditions and lightings (time of day).

2. Airborne monitoring (carries out in emergency situations discovering and recording on base of satellite monitoring). It carries out operatively, and it main task is correct definition of scales and types pollutions including volume of works on liquidation emergency situations. For these purposes use specially equipped research aircrafts onboard of that install and exploit following remote sensing equipments:

- digital photos- and video cameras;
- LIDAR;
- SAR;
- passive microwave radiometer.

Here to note that two last airborne remote sensing systems are all weather, and its using independent on clouds, fogs, mist, precipitations and other atmospheric phenomena availability.

All information in real positions and time put on research aircraft onboard computer, here also has inside computer net (so-named intranet). Marine environmental monitoring final results are images of discovered and recorded pollutions including information about its types, and mapping.

The main advantage above approach is possibility regular monitoring of considerable sea surface area for short very time and in minimum possible financial expensive with high degree reliability and qualitative. As show independent on economical calculation of several experts total expensive for liquidation of even very small accident situation will be in 3-6 times more in comparison with annual air-space monitoring.

Texture-based random forest classification of sub-Antarctic vegetation on Macquarie Island from QuickBird and WorldView-2 imagery

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Macquarie Island is a unique sub-Antarctic island and a World Heritage Area that has rapidly changed under the pressures of rabbit grazing. An increase in the rabbit population in the last few years has resulted in extensive destruction of unique sub-Antarctic vegetation communities, which has resulted in erosion and landslides, and it has had a devastating impact on the population of many burrowing seabird species. Up-to-date and accurate spatial data, such as vegetation maps are of crucial importance for sustainable management of the island.

In this study, we developed a new texture-based classification algorithm for very high resolution satellite imagery to classify vegetation communities on Macquarie Island. A tussock grass that is characteristic for the coastal slopes has been steadily disappearing under the pressures of rabbit grazing. The aim of this study was to use QuickBird and WorldView-2 imagery acquired in March 2005 and December 2009 respectively to map and quantify the extent and change of tussock grass as a `health indicator' of the island. Wavelet texture measures were developed and extracted from the panchromatic image band and combined with the multispectral bands to incorporate both spatial and spectral information. A random forests classifier was applied to identify tussock grass and other vegetation types from the satellite images. The texture-based random forest classifier was tested on a composite of textures derived from the original QuickBird image. We showed that the incorporation of wavelet texture measures improved the classification accuracy by ~13% to almost 100%. Additionally, random forest variable importance measures showed that the incorporation of texture helps to identify tussock areas. Classification of the 2005 QuickBird and 2009 WorldView-2 images resulted in an accuracy of 86% for the tussock class, which was verified by field samples. Post-classification change detection showed a 46% decrease in tussock area during these five years. We conclude that the wavelet-based texture measure derived from the panchromatic band is a valuable addition to the spectral information from the multispectral bands. We also identify the random forest classifier as a superior classification technique for complex non-parametric classification problems. We demonstrate that our approach is highly suitable as a semi-automated, objective, and repeatable approach towards vegetation classification from very high resolution satellite imagery.

A strategy for producing predictive bedrock maps of Canada's North

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The Remote Predictive Mapping Project (RPM), recently renamed to Systematic Mapping of Arctic Canada by Remote Techniques (aka SMART) is focused on developing efficient and timely mapping of large areas of the North that require up-dated and /or more detailed bedrock mapping. This poster demonstrates a step-by-step approach for accomplishing this task using an example from the Hall Peninsula in central Baffin Island. This area was last mapped in the 1950's and both bedrock and surficial geology requires updating. We are accomplishing this task by applying both visual and computer-assisted processing techniques to various geoscience data including remotely sensed (LANDSAT and SPOT), geophysical (magnetics) and topographic (DEM) data to extract both lithological and structural information. We incorporate legacy geological data (existing maps, field observations) to assist in geologically calibrating the predictive maps we produce.

The interpretation methods we are utilizing and developing as well as the technology we are employing are presented in this poster. In addition examples of the proto-type predictive bedrock maps we are producing are presented and discussed.

The remote predictive mapping process begins with the acquisition, processing, and geological interpretation of avail-able remotely sensed data sets, and results in predictive maps that outline interpreted units and structures in the study area. RPM can be either completed in isolation from field-based mapping or can be intimately inte-grated with it in order to ground truth the interpretation as field mapping proceeds. Figure 1 shows a sum-mary of the RPM process integrated into the work flow of a geological mapping project. Regardless of whether the interpreta-tion of remotely sensed data is fully integrated into a geological mapping project or not, the following pro-vides a systematic outline of RPM work flow.

64

Abstracts of Posters

Eurasian Arctic Greening Reveals Teleconnections and the Potential for Novel Ecosystems

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Arctic warming has been linked to observed increases in tundra shrub cover and growth in recent decades based on significant relationships between deciduous shrub growth/biomass and temperature. These vegetation trends have been linked to Arctic sea ice decline and thus to the sea ice/albedo feedback known as Arctic amplification. However, the interactions between climate, sea ice, and tundra vegetation remain poorly understood. Here we reveal a 50-year growth response over a >100,000 km2 area to a rise in summer temperature for alder (Alnus) and willow (Salix), the most abundant shrub genera respectively at and north of the continental treeline. We demonstrate that whereas plant productivity is related to sea ice in late spring, the growing season peak responds to persistent synoptic-scale air masses over West Siberia associated with Fennoscandian weather systems via the Rossby wave train. Substrate is important for biomass accumulation, yet a strong correlation between growth and temperature encompasses all observed soil types. Vegetation is especially responsive to temperature in early summer. These results have significant implications for modelling current and future low arctic vegetation responses to climate change, and emphasize the potential for structurally novel ecosystems to emerge from within the tundra zone.

Expansion and patch dynamics of alder shrublands in the Siberian Low Arctic: evidence from remote-sensing spanning the Space Age

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Declassified imagery from the KH-4B "Corona" and KH-7 "Gambit" Cold War satellite surveillance systems (1963-1972) are a unique, high-resolution dataset that establishes a baseline for landcover-change studies in the Russian Arctic spanning 6 decades. Coverage is particularly extensive in northwest Siberia and Chukotka. We co-registered Corona/Gambit and modern high-resolution imagery for five ~65 km^2 Low Arctic sites—one each in southern Yamal, Taz, and Taymyr peninsulas, and two in Chukotka—and quantified changes in the distribution and extent of tall shrublands dominated by Siberian alder (*Alnus fruticosa* spp. *sibirica*) using a point-intercept sampling approach. We also produced Landsat TM/ETM+ time-series of Normalized Difference Vegetation Index (NDVI) for the northwest Siberian sites for ~1985-2011, and applied pixel-based linear regression to identify areas with significant trends in vegetation productivity. We photo-interpreted modern high-resolution imagery to determine important geomorphic processes and physiographic units associated with changes in shrubland extent and vegetation productivity; photo-interpretation was facilitated by field data from the Kharp site in the southern Yamal region.

Alder shrubland cover increased at all five sites; in northwest Siberia, shrubland extent increased by 5% (Taz), 8% (Kharp), and 31% (Taymyr), and by 9% at both Chukotkan sites. In northwest Siberia, alder expansion was closely linked to disturbances in permafrost related to patterned-ground (Kharp and Taymyr) and active-layer detachments (Taz). At the Chukotkan sites, most alder expansion occurred on hillslopes (Pekul'ney), and almost exclusively on floodplains (Velikaya); we also observed modest increases in Siberian dwarf pine (*Pinus pumila*). The close correspondence between expanding shrub patches and disturbance processes indicates that sparsely-vegetated, mineral-rich seedbeds strongly facilitate alder recruitment, and that the spatio-temporal attributes of disturbance mechanisms are a key determinant of landscape susceptibility to shrub expansion. Spatial analyses of expanding shrub patches indicates that most shrub expansion occurs incrementally from pre-existing stands, and suggests that expansion rates are positively correlated to shrubland edge-extent.

Virtually all significant Landsat-derived spectral changes indicate "greening", but intensity and spatial patterns differed markedly at the three sites with widespread, moderate greening at Kharp, very limited greening at Taz, and widespread strong greening at Taymyr. At all sites, most areas of strong greening coincided with known shrub expansion areas, and most "background" greening coincided with long-established shrublands. By linking significant spectral changes to known shrub expansion areas, we have developed spectral signatures for this type of landcover change and are applying them to regional-scale, Landsat-based analyses of alder shrubland dynamics elsewhere in the northwest Siberian Low Arctic.

Land use/cover changes and their effects on reindeer husbandry in northern Finland over the past four to six decades

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Forestry, tourism, nature conservation, reindeer herding and recently, mining are major drivers of land use/cover changes in northern Finland. Reindeer husbandry is the oldest of these land use forms. There have been conflicts between the new land use forms and reindeer husbandry because of resource utilization for different purposes and subsequent adverse effects on each other. We studied land use/cover changes and their effects on reindeer husbandry in the Lappi reindeer herding district in eastern Lapland over the past four to six decades. A series of Landsat MSS, TM and ETM+images (1972, 1987, 1993 2005, 2011) and Corona images (1977) were used to detect land cover changes in a study area of 4553 km^2. More detailed analyses of land cover changes were carried out in four locations within the study area using a series of aerial photography from 1950's to 2000's. Information of reindeer herding system and its changes in the study region were derived from old maps and interviews with reindeer herders.

The results highlight various changes in land cover/use resulting from clear-cutting, road construction, use of herbicides and the construction of artificial lakes. The area of young forests had significantly increased in the landscape. Old forests were mainly found in protected areas (national and nature parks, wilderness areas). Further, the density of the road network had noticeably increased as a result of the construction of forestry roads and tourism. From the reindeer husbandry viewpoint the number and the extent of disturbances in the landscape have increased during the past decades. Forestry has mainly negative effects on reindeer husbandry through the reduced amount of ground-growing and arboreal lichens. Artificial lakes have reduced the area of suitable pastures and disturbed pasture rotation system. Further, increased tourism in Urho Kekkonen National park have disturbed reindeer herding in fjell areas. Cumulative impacts of land use/cover changes are reflected to the spatio-temporal land use of reindeer husbandry as reindeer herding system tries to adapt to new conditions and shrinking pasture land.

Use of MODIS data to analyse spectral properties of land cover types for improved mapping of the growing season in Northern Fennoscandia

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The study area of northern Fennoscandia is an ecologically heterogeneous region in the arctic/alpine-boreal transition area and includes northern Norway, Sweden, Finland, and Kola Peninsula in north-western Russia. Changes in the timing of the growing season (phenology) are among the most sensitive indicators of changes in temperatures in the northern areas. The aim of this study is to map the trends, extreme years, and mean date in onset, end and length of the growing season in the study area. To map the growing season we use MODIS data, the MOD09A1 product, with 8-days composites, 500m resolution and 7-bands reflectance for the 2000 to 2011 period. The extensive calibration process includes three main steps for cloud removal. The cloud mask used in the MODIS data (QA-values) have lot of errors, and in the first step we developed our own cloud detection procedures based on the 7-bands, as well as visual evaluation of the cloud cover of each 8-days period. In the second step we replace the cloudy pixels based on temporal information (the periods before and after or median values form years before/after). In the final step we smoothed the different indices and the 7-bands using the TIMESAT program.

Close cooperation between north-western Russia and the Nordic countries within phenological research has been established in the region, and most of the field observation data are harmonized and can be compared across the borders. A phenology index based on several species and phenophases were calculated for the autumn period. To map the growing season we first analysed the spectral reflectance of the 7-bands of different land cover types during the growing season, this to identify which band combinations that best monitor the onset and end of the growing season. Finally, a combined pixel-specific threshold and decision rule-based mapping method was used to determine the onset and end of the growing season, by using thresholds with best fit to the field data/phenology index. The results show large variations in the onset of growing season from year-to-year during the last 12 years. The resulting phenological maps can be used in a broad range of ecological and climate change studies. The project was funded by the Nordic Centre for Spatial Research (Nordregio).

Remote sensing assessment of the feedbacks between the climatic, environmental and societal changes in Siberia over 30 years: the CLASSIQUE project

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Climate change in Siberia and more generally at high latitudes, is impacting strongly the environment and the societies. If the present climate warming evolves as projected, these impacts are likely to increase, greatly affecting ecosystems, cultures, lifestyles and economies. The CLASSIQUE French research project is focused on these questions, with a special attention to land cover evolution, forest vulnerability and permafrost reduction in Siberia. It mobilizes climatologists, hydrologists, agronomists, demographers and specialists of scientific mediation in a trans-disciplinary effort to better quantify (1) future changes of climate and vegetation properties in Siberia; (2) the consecutive evolution of the agricultural potential of the region; (3) the demographic and societal effects of these changes; and (4) the interactions and feedbacks induced.

The chosen approach aims to develop integrated models able to predict the evolutions of land cover and hydrology and the links with the Russian population. To predict the future impacts of climate change on Siberian ecosystems, the two French vegetation models (the ISBA and the ORCHIDEE models) will be used and various databases will be developed for their validation on the past thirty years and to identify possible trends. A large interest will be devoted to remote sensing archives which provide surface monitoring and spatial integrated variables on the last thirty years. Various satellite products will be gathered and developed at different scales to assess land surface variables like, land cover / land use and changes, albedo, surface temperature, fire and vegetation dynamics as well as soil moisture, wetlands, snow cover, freezing and thawing periods, etc. A presentation of preliminary products developed and satellite database status will be presented.

An Emerging Paradigm for Surficial Geological Mapping of Arctic Canada at the Geological Survey of Canada

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Terrain analysis of glaciated terrains is approaching a "tipping point" as remotely sensed digital data and digital elevation models become more available and cost-effective alternatives to aerial photographs. The challenge in remote predictive mapping (RPM) of glaciated landscapes is recognition of the series of complex steps in the traditional cogitative terrain analysis process and encapsulating them within computational workflows based on image analysis and statistical modelling. Within the SMART (Systematic Mapping of Arctic Canada by Remote Techniques) project of Geo-Mapping for Energy and Minerals Program (GEM), a methodology and data handling framework is being developed to improve mapping productivity.

SMART mapping is a complex challenge that involves: i)development of a science language for glaciated terrain, ii) integration of expert knowledge and legacy datasets, iii) parsing knowledge into machine operable components (morphology, texture, shape etc.), iv) classification of attributes, v) evaluation of various geoscience data types (i.e. remotely sensed , topographic and various calculated derivative images) for surficial mapping, and vi) statistical analysis, modelling and expert systems integration of the diverse landscape attributes within a geoscience data stack. Morphology, for example, is being extracted through analysis of Digital Elevation Model data and derivatives. This work forms the basis for specific landform analysis (e.g. eskers) and as a component of the data stack. Material (texture, lithology) types are primarily being captured using remotely sensed data (LANDSAT, Radar) in concert with pixel-to-pixel-based classification algorithms (e.g. Robust Classification Method (RCM)).

Lake shape and landforms are being analyzed using form statistics and object-orientated, landscape-segmentation techniques. Spatial association of various landform metrics provides a challenge that is being undertaken using density functions and integration of specific expert interpreted data layers (drumlin, esker, etc.). Integration of this diverse suite of data layers is being completed using several techniques, including: statistical approaches, decision trees, fuzzy sets, and expert system approaches.

Two specific case studies are highlighted that represent new approaches to surficial geological mapping depending upon terrain complexity, study area scale, data availability and study resources. The Central Baffin case study illustrates mapping a large area at a scale of 1: 500,000 from LANDSAT and DEM derivatives: it serves as a proto-type for the SMART "grey space" mapping initiative as well as the GEM Tri-Territorial Surficial Geology Compilation Project. A more detailed and modelling-intensive approach is being applied in the McKay Lake (NTS 75M) case study near Great Slave Lake using DEM, SPOT 4, LANDSAT data and a fuzzy set modelling approach. These examples illustrate the process from an initial predictive surficial materials map to a derivative predictive surficial

geology map which can then be used as an aid to field-supported mapping. The transition from cognitive interpretation and recording of terrain elements to semi-automated approaches is a considerable challenge that requires careful consideration of the conceptual and semantic models employed by the geologists. The requirement to revisit the classification lexicon of glacial landscapes, landforms and geological legends will result in improved perspectives and understanding of the signatures and processes of the glaciated landscape of northern Canada derived from remote predictive mapping.

A strategy for producing predictive bedrock maps of Canada's North

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The Remote Predictive Mapping Project (RPM), recently renamed to Systematic Mapping of Arctic Canada by Remote Techniques (aka SMART) is focused on developing efficient and timely mapping of large areas of the North that require up-dated and /or more detailed bedrock mapping. This poster demonstrates a step-by-step approach for accomplishing this task using an example from the Hall Peninsula in central Baffin Island. This area was last mapped in the 1950's and both bedrock and surficial geology requires updating. We are accomplishing this task by applying both visual and computer-assisted processing techniques to various geoscience data including remotely sensed (LANDSAT and SPOT), geophysical (magnetics) and topographic (DEM) data to extract both lithological and structural information. We incorporate legacy geological data (existing maps, field observations) to assist in geologically calibrating the predictive maps we produce.

The interpretation methods we are utilizing and developing as well as the technology we are employing are presented in this poster. In addition examples of the proto-type predictive bedrock maps we are producing are presented and discussed.

The remote predictive mapping process begins with the acquisition, processing, and geological interpretation of avail-able remotely sensed data sets, and results in predictive maps that outline interpreted units and structures in the study area. RPM can be either completed in isolation from field-based mapping or can be intimately inte-grated with it in order to ground truth the interpretation as field mapping proceeds. Figure 1 shows a sum-mary of the RPM process integrated into the work flow of a geological mapping project. Regardless of whether the interpreta-tion of remotely sensed data is fully integrated into a geological mapping project or not, the following pro-vides a systematic outline of RPM work flow.

Sixty years of landscape change within an arctic oilfield, Prudhoe Bay, Alaska

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The Prudhoe Bay oil field in Alaska is the largest industrial development in the Arctic. Exploration of the area began in the 1960s, oil was discovered in 1968, and initial development occurred in the 1970s. The area has extensive aerial photography coverage used for planning, mapping and monitoring. The earliest aerial photography used for this current study was from a 1955 U.S. Air Force mission (Earth Explorer, USGS). This black and white photograph, at 1:50,000-scale resolution, documented the pre-development landscape. In the early years after oil discovery at Prudhoe Bay, air photos were flown occasionally to meet industry needs. More recently, digital aerial photos have been collected every year.

In cooperation with the oil industry, a time-series of aerial photographs was assembled to document development and its associated impacts (Orians et al. 2003). Detailed photo-interpretation of three 25 km^2 areas of intensive development in the central part of the Prudhoe Bay oil field documented the impacts up to 1983, including photographs from 1965, 1970, 1972, 1973, 1977, 1979 and 1983 (Walker et al. 1987). Aerial photographs from 1990, 2001 and 2010 were used to update the mapping of one of these areas, which includes Pump Station 1 (the beginning of the trans-Alaska pipeline), several drill sites, gravel mines in the Putuligayuk River floodplain, and the main Prudhoe Bay study areas of the International Biological Programme Tundra Biome (Brown 1975). An integrated mapping approach combined vegetation and surface form maps with disturbance maps in a GIS (Walker et al. 1987).

Almost half of the area experienced some change to the vegetation during the sixty years of the study (46%): 11.5% by direct industrial impacts (roads, gravel pads, etc.), 19% by indirect effects such as flooding caused by blocked drainage, 2% by natural changes such as lake or river erosion. Direct anthropogenic impacts increased little after 1990, but indirect effects continued to increase. 18% of the area was affected by ice-wedge thawing and associated ponding by 2010. This effect was most concentrated near roads, and appeared to continue a non-linear increase in anthropogenically-generated thermokarst first detected in 1983 (Walker et al. 1987). Ice-wedge degradation was also common in more isolated parts of the map and may be indicative of the effects of recent climate warming that has been detected in other studies on the Arctic Coastal Plain (Jorgenson et al. 2006).

Plans for future analysis include 1) developing more quantitative techniques to measure ice-wedge degradation, 2) assessing the relationship of these changes to infrastructure and various geobotanical features, 3) conducting the same analysis for the other two map areas at Prudhoe Bay, and 4) assessing the utility of Landsat and Quickbird imagery to provide broad-area assessments of infrastructure and landscape changes that could be applied to the entire area of development on the North Slope.

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Mapping downward shortwave radiation using MODIS atmospheric products

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1. Introduction

Downward Shortwave Radiation (DSR) plays an important role in the oceanic and atmospheric general circulation. There are few radiation observations over ocean and Polar Regions. Satellite data are the only source for detailed knowledge of spatial-temporal DSR distribution. Due to the gradual degradation of spatial resolution and data reliability for the geostationary satellites at higher latitude, this study presents a scheme for retrieving all-sky DSR that exploits the new suit of atmospheric products generated by the MODIS science team.

2. Data

The input to the model is acquired from MODIS atmospheric data which can be downloaded from the website freely (http://ladsweb.nascom.nasa.gov/data/): total precipitable water is acquired from the MODIS Atmosphere Level 2 product (MOD05/MYD05); cloud optical thickness from the MODIS water product (MOD06/MYD06); sensor zenith angle, sensor azimuth angle from the MODIS geolocation product (MOD03/MYD03) which are used to correct the atmospheric products to nadir viewing angles. The Terra and Aqua satellite platform cross the Equator during the daytime at approximately 10:30AM local time on the descending node, and 13:30PM local time on the ascending node, respectively.

3. Methodology

Total solar irradiance consists of three components: direct solar irradiance (I_{dir}), sky diffuse irradiance and reflected irradiance from ground. I_{dir} can be expressed as

$$I_{dir} = I_o \cdot T_{clear} \cdot E_R \cdot \sinh$$

(1)

Where I_0 is the extraterrestrial solar irradiance, E_R is the sun-earth distance correction factor, T_{cloudy} and T_{clear} represent the transmittance of the cloud layer and the clear layer respectively, h refers to the sun elevation.

Diffuse irradiance (I_{dif}) at ground level is treated as a combination of two individual components, i.e., sky diffuse irradiance (Rayleigh diffuse irradiance and aerosol diffuse

irradiance), multiple backscattering between surface and sky. Parameters for diffuse irradiance are cited from Gueymard (*Gueymard, 2008*).

Total solar irradiance under cloudy sky (I_{cloud}) is considered to be a function of global irradiance and cloud transmittance (T_{cloud}). The cloud transmittance is interpolated from the look-up table given in Stephen (*Stephen et al., 1984*)

$$I_{cloud}=(I_{dir}+I_{dif}) \times T_{cloud}$$

(2)

Daily DSR can be calculated by integrating the irradiance from sunrise to sunset in 30 minutes intervals

4. Results and discussion

As the DSR observations of the Polar Regions are unavailable, the proposed model is validated using observations from 11 stations within the Qinghai-Tibet Plateau.

The correlation coefficient of modeled daily and averaged 10 days of global solar radiation was higher than 0.71 and 0.85 respectively, except for Guoluo with R^2 of 0.67 and 0.79.

There maybe three possible error sources:

(1) The conflict of the spatial resolutions between the observed and simulated data.
(2) The spatio-temporal resolution of the MODIS atmospheric data is a bit rough for the Qinghai-Tibet Plateau.
(3) Another possible reason for the biases may be introduced by the MODIS cloud-detection algorithm with a maximum uncertainty of 200%.

Application of the remote-sensing data to permafrost mapping: a case study in Central Yamal

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Permafrost mapping and modeling is based on the understanding of the main controls affecting permafrost parameters: ground temperature, active-layer thickness, cryogenic processes. In the Tundra zone, remote sensing can provide necessary information on spatial distribution of surficial parameters represented by vegetation type and coverage. Vegetation serves on one hand as an insulation ground cover (moss, lichens), and as an entrapment for snow (shrubs), and on the other hand vegetation indicates drainage conditions (sedges for wet environments, lichens for dry ones, mosses and shrubs for mesic).

A case study was undertaken at central Yamal at the research station Vaskiny Dachi. In summer 2011 a 1.5 km long transect crossing main geomorphologic units of central Yamal was established and subject to multipurpose field study. Detailed description of vegetation and numeric parameters characterizing tundra complexes was followed by active-layer measurements. Main complexes affecting permafrost were subdivided into main classes, such as barren surfaces, shrub-dominating, moss-dominating and sedge-dominating communities.
Thus there exists detailed ground data (Brown-Blanquet, spectro-radiometry, Munsell colour value for vegetation) to guide the processing and the interpretation of remote-sensing data. The optical satellite data base is a high-spatial resolution GeoEye-1 acquisition with 0.5 m ground sampling distance acquired at the 15th August in 2009 (NGA license, University Alaska Fairbanks, NASA LCLUC Yamal).

Spectral analyses were performed to extract surface classes: surface waters, barren surface, shrub-dominant, moss-dominant and sedge-dominant communities. Spectral discrimination of surface waters was done using a threshold value in the near infrared band 4. The barren surface was discriminated using the NDVI.

Various spectral analyses were tested to separate shrubs-dominated, moss-dominated and sedge-dominated surfaces. Processed were 4 Principal Component (PC) bands, including masking of surface waters. The lower PC bands contain the subordinate information that can often not be extracted using standard classification methods. PC bands 2 and 3 were interpreted to contain information on 'greenness' and 'moisture and structure', respectively. At this stage, the shrubs were manually digitized guided by the structure information in PC band 3.

The 'greenness' can also analytically be calculated as chlorophyll absorption depth using the GeoEye bands green (Band 2), red (Band 3) and near infrared (Band 4). The spatial pattern of the calculated chlorophyll absorption depth correlates with the spatial pattern of PC band 2. Thus, the assignment of the sedge-dominance to PC band 2 proves to be acceptable and automatically extractable.

The sedge-dominated areas exhibit higher maximal GeoEye-NDVI values compared to shrub-dominated. The lower NDVI range for sedge-dominated areas overlaps with the NDVI range for shrubs. Therefore, the NDVI is not a clear proxy for discrimination of shrubs and sedges. The late-summer state of shrub-dominated surfaces exhibit more reddish-brownish colours, whereas sedge-dominated areas inherent the green colour range.

Future effort will be directed to compilation of the Vaskiny Dachi permafrost map based on the correlation of ground temperature and active layer depth with the surface classes.

Texture-based random forest classification of sub-Antarctic vegetation on Macquarie Island from QuickBird and WorldView-2 imagery

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Macquarie Island is a unique sub-Antarctic island and a World Heritage Area that has rapidly changed under the pressures of rabbit grazing. An increase in the rabbit population in the last few years has resulted in extensive destruction of unique sub-Antarctic vegetation communities, which has resulted in erosion and landslides, and it has had a devastating impact on the population of many burrowing seabird species. Up-to-date and accurate spatial data, such as vegetation maps are of crucial importance for sustainable management of the island.

In this study, we developed a new texture-based classification algorithm for very high resolution satellite imagery to classify vegetation communities on Macquarie Island. A tussock grass that is characteristic for the coastal slopes has been steadily disappearing under the pressures of rabbit grazing. The aim of this study was to use QuickBird and WorldView-2 imagery acquired in March 2005 and December 2009 respectively to map and quantify the extent and change of tussock grass as a `health indicator' of the island. Wavelet texture measures were developed and extracted from the panchromatic image band and combined with the multispectral bands to incorporate both spatial and spectral information. A random forests classifier was applied to identify tussock grass and other vegetation types from the satellite images. The texture-based random forest classifier was tested on a composite of textures derived from the original QuickBird image. We showed that the incorporation of wavelet texture measures improved the classification accuracy by ~13% to almost 100%. Additionally, random forest variable importance measures showed that the incorporation of texture helps to identify tussock areas. Classification of the 2005 QuickBird and 2009 WorldView-2 images resulted in an accuracy of 86% for the tussock class, which was verified by field samples. Post-classification change detection showed a 46% decrease in tussock area during these five years. We conclude that the wavelet-based texture measure derived from the panchromatic band is a valuable addition to the spectral information from the multispectral bands. We also identify the random forest classifier as a superior classification technique for complex non-parametric classification problems. We demonstrate that our approach is highly suitable as a semi-automated, objective, and repeatable approach towards vegetation classification from very high resolution satellite imagery.

Integrating Airborne Thematic Mapper and in situ data to better characterise glacier facies

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Here we present work using multispectral imagery from the Airborne Thematic Mapper (ATM) to build a classification scheme for surface zones of arctic glaciers and icecaps constrained by recently collected data. Previous studies of snow spectral response indicates that the ATM's spectral and spatial resolution will allow for sensitivity in measuring the important but elusive firn line.

In design, the ATM is similar to Landsat's Enhanced Thematic Mapper but with key improvements to spatial (potential submeter vs. 30 m) and spectral (a near infrared band 0.91-1.05 μm) resolution. This research builds on promising techniques used with Landsat data, application of previously unused ATM data, and potentially the integration of associated surface elevation data where appropriate with the goal of successfully and reliably identifying the extent of major glacier facies.

Compounding the already problematic issue of snow facies distinction, most published classification schemes suffer from a lack of reliable ground-truth to confirm identification of glacier facies based solely on remotely sensed data. Therefore, in addition to previously collected ATM data, associated fieldwork to Ny-Ålesund, Svalbard was conducted during August 2010 and Langjökull, Iceland during August 2011. Spectra highlight differences in the reflective properties of new snow, old snow, spatially variable ash cover on melting snow, melting ice, debris-littered melting ice, and the variability of surface types on one glacier and between glaciers.

The work presented here uses the collected *in situ* surface reflectance data to inform interpretation of ISODATA classification schemes, will provide end member points for spectral mixing studies, and gives a starting point from which to develop useful analysis strategies for remotely sensed data including timeseries of Landsat imagery. In the future, accurate facies measurement will hopefully provide an effective mass balance proxy which facilitates global glacier monitoring, mass balance studies, water resource availability, and quantification of the largely uncertain contribution of small glaciers and icecaps to global sea level rise.

Time series of aerial photographs as a proxy of vegetation change in boreal peatlands

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Peatlands have undergone significant changes due to the intensive drainage campaigns since 1950's in Finland. Drainage in the surrounding areas has affected hydrology also of many peatlands that have remained undrained. We investigated changes in a typical undrained aapa mire in Eastern Finland. Drainage in the catchment area surrounding the aapa mire started in 1968 and led to major changes in the mire ecosystem. Aerial photographs provide a detailed data source for investigation of vegetation changes in aapa mires.

In the first part our study, we utilize a false-color image from the year 2009 and second we investigate black and white image series from the years 1941, 1953, 1965, 1974, 1984, 1995, 2005 and 2009.

The principal goal of the study is to provide information of the present and past vegetation of the investigated aapa mire. First aim of the research is to create new methods to interpret vegetation type reflection signatures from aerial false-color photographs (2009). We test if the image classification can be created on basis of plant community composition, using vegetation plot data collected in the field in summer 2011. Classes based on plant community composition are created using cluster analysis. The aerial false-color photograph is then classified with minimum distance- and maximum likelihood methods. Same image is also classified "traditionally" using unsupervised and supervised classifications. Accuracy of the different classifications will be tested using field data and results are compared post hoc.

Second aim of the research is to investigate how the aapa mire has changed since the drainage of the surrounding areas started in 1968. Here, we are using both paleobotanical data (peat samples) and aerial photographs. Old aerial photographs are homogenized and classified into five classes representing the main vegetation types. We are detecting the changes comparing the classification results and by visual interpretation. Preliminary results revealed a dramatic shift from fen vegetation to the nearly complete dominance of peat mosses (Sphagnum) within three decades after the catchment disturbance.

Palsa decay studied with aerial photography and RTK GPS measurements

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Palsa is a form of discontinuous permafrost in the circumpolar zone. Palsa are peat mounts with a core of permanently frozen peat, ice and mineral soil. The palsa can be from one to several meters high, dominating an otherwise flat mire area. There are several studies which indicate that palsa's are melting and decaying as a result of climatic warming. Weather conditions vary yearly and affect the depth of the active layer. The palsas under study are located in the Kilpisjärvi area, Finland, about 470 meters above sea level (lat 68° 54' lon 20° 58) (Laassaniemi and Peera).

Two palsa were measured using Real Time Kinematic GPS with XYZ accuracy of one cm. A measurement grid with two meter interval was defined over each palsa, both have approximately 200 points. Measurements were carried out yearly in the last days of August (2007-2011). Active layer depth of each point was measured with an active layer probe. With ArcGIS we created 3-D models of palsa and yearly active layer surfaces. Weather data used is from the Kilpisjärvi climate station allocated about 15 km north of the study sites (1951-2011).

We also used a time serie of aerial photographs to detect the decay process of palsas (1959, 1985, 1997's and 2000. Both palsa's has experienced decay especially along the edges. The palsa in Laassaniemi has large collapsing side towards a thermokarst pond, here the core has collapsed more than one meter during the study period. In the 1959 image there are no signs of a thermokarst pond.

Detailed RTK high accuracy GPS based palsa monitoring opens new aspects in palsa research. Combining historical aerial photographs the time span of the study can be stretched up to 50-60 years. Combining five years of detailed field data with 50 years of historical aerial photographs we can accurately follow the development of a palsa and its correlation to climatic factors. Both palsa's investigated were experiencing significant decay during the study period.

Detection of human induced disturbances and grazing impacts on tundra vegetation state: preliminary results of a large scale comparative remote sensing study

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Despite being a relatively pristine region, the Arctic zone is characterized by a multitude of natural and anthropogenic disturbances. Remote sensing provides an efficient tool to investigate human induced changes in land cover and land use. Our main objective has been to investigate local to landscape/regional scale impacts of human activities on the tundra ecosystems in Russia, Canada and Alaska. We analyse very high resolution remote sensing images (Quickbird-2, GeoEye and WorldView II), in concert with Landsat imagery and old Corona imagery, to assess how traces of human use like infrastructure and ATV-tracks around settlements influence local habitat transformation. Furthermore, we assess the impact of different grazing regimes, in particular the presence of semi-domestic or wild reindeer on vegetation states, such as the abundance and configuration of shrub/willow thickets and state of lichen cover. The study comprise areas surrounding 18 settlements in Russia, Alaska and Canada (ca 10 x 10 km), which were chosen according to a design of spatial contrasts in governance and socio-economic conditions. In addition to the areas directly surrounding the settlements, which are likely to be intensely used, areas of extensive use were chosen at 30 km from the settlements (ca 9 x 9 km). A protocol for analyzing the images has been developed on the basis of studies in Khatanga (Russia) and Brevig Mission (Alaska). The images were searched systematically for traces of human use such as ATV-tracks, roads, air fields, land-fills, garbage deposits, fences, camps, activity areas, buildings and mines. All observed objects were digitized using ArcGIS. Satellite image classification using both unsupervised (clustering) and supervised (max-log-likelihood and spectral unmixing) has been carried out on the imagery. We focused on vegetation and land cover types which are predicted to represent different states in transitions induced by grazing or physical disturbance such as driving (willow thickets – productive meadows; lichen tundra – moss tundra – grass tundra; different types of mires and wetlands). The protocol includes field observations and in-situ photo documentation for satellite image classification and interpretation, vegetation classification and disturbance evaluation. Roads, driving tracks and ATV tracks are the main traces of human use identified on the images likely to impact habitats such as wetlands and mires. For instance, in Brevig Mission 48.2 km of tracks in the intensive use area and 18.2 km in the extensive use area has been documented. In Chesterfield Inlet in Nunavut, Canada the numbers are respectively 28.3 km and 0 km. Apart from a clear connection to settlements and activity areas near the settlements, it is a tendency that the tracks are related to activities around water bodies such as rivers and lakes (fishing activities). This is the case both in the intensive and extensive use areas, in North America and Russia. Our results are relevant to land use management and will contribute to the understanding of how tundra vegetation will change under the joint influences of climate change and human use.

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